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IRON ORES

IRON ORES

THEIR OCCURRENCE, VALUATION AND CONTROL

BY

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PREFACE

The material presented in this volume has been worked over, at intervals, during many years of professional activity; and certain sections have, as later noted, been published in various technical journals and in private and official reports.

The volume as it now stands represents an attempt to discuss iron ores not merely in their geologic and technical relations, but in their more general relations to industrial conditions. The field thus outlined is broad, and the risk of failure is correspondingly great. But on the other hand there have been exceptional opportunities for studying the iron-ore situation from several widely different standpoints, and something more than a purely technical treatment seemed to be both justified and desirable. The industries based upon iron ores are of interest, directly or indirectly, to the entire business and financial world; and have also to some degree become matters of political concern. Any adequate discussion of the general iron-ore situation must therefore take into consideration many factors not commonly regarded by the geologist or the engineer, and too often passed by as not susceptible of exact definition or scientific treatment. It is hoped that this volume will prove to be, if not conclusive, at least suggestive in these regards.

Beginning with some consideration of the natural abundance and wide distribution of iron, the manner in which this disseminated iron is concentrated into workable ore deposits is discussed in considerable detail. It may be noted, in this connection, that the sedimentary ores are given space more nearly commensurate with their overwhelming importance than has been common practice.

The second section of the volume is devoted to discussion of the various factors affecting the value of iron ores and the valuation of ore deposits. An introductory chapter summarizes the basal factors concerned in these matters. This is followed by a discussion of prospecting or exploratory work, in which for the first time an attempt is made to indicate the manner in which theories of origin actually bear upon the examination of ore deposits. Following this are chapters on mining costs, concentrating possibilities, and furnace and mill requirements, so far as any of these matters bear upon the subject of ore valuation. Later chapters of this section treat of prices, markets and other financial aspects of the problem.

Descriptions of the more important ore deposits of the world are contained in the third part of the book. In preparing these descriptions, an attempt has been made to consider the deposits in the light of their present and possible industrial importance. Deposits of local importance and those which are of interest solely as geologic occurrences are not described, and individual mines and ore properties are not noted except as illustrating general types. The attempt has been to give, with regard to each important ore field, sufficient data concerning its location, type, ore grade, shipments and reserves to justify conclusions expressed by the writer, or to enable the reader to form his own conclusions, as to the present and possible future importance of that field. In most cases very full reference lists are included, so that further details can be looked up as desired.

The final section of the volume deals with certain questions of very general interest and great importance. Estimates are given covering the known iron-ore reserves of the world, and the bearing of these estimates upon the probable future development of the iron industry is discussed in some detail. Particular attention is paid to conditions affecting the American iron industry, regarding its own internal development, its relations to foreign competition, and its relation to the State. It is probable that

public interest in the last point mentioned will continue until laws are brought into harmony with industrial conditions.

In preparing this book, data have been drawn from a large number of published and unpublished sources, covering both the work of others and my own. In addition to the specific credits given in the text, my acknowledgments are due to the editors of various journals, for permission to re-publish certain sections which I originally published in their columns. The *Engineering Magazine*, *Iron Trade Review*, *Iron Age*, *Engineering and Mining Journal* and *The Annalist* are my principal creditors in this regard.

E. C. E.

WASHINGTON, D. C.
June 18, 1914

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IRON ORES

THEIR OCCURRENCE, VALUATION AND CONTROL

CHAPTER I

THE INDUSTRIAL STATUS OF IRON

"Gold is for the mistress—silver for the maid
Copper for the craftsman, cunning at his trade.
Good," said the Baron, sitting in his hall
"But Iron—Cold Iron—is master of them all."

Rewards and Fairies.

Certes above rare metals iron aids man in need ever.

England's Commonweal Expounded.

A proposition to which both the modern Imperialist poet and the ancient Puritan divine can give their assent must needs be one of very broad and general application; and the two and a half centuries which have elapsed between the two statements regarding the status of iron show that we are dealing with something more than a temporary situation.

It is of course the veriest commonplace to say that iron is the cheapest, the most abundant and the most useful of all the metals now employed by man. But, as is so often the case with matters of common knowledge, the very familiarity of such statements is apt to prevent careful examination of the basis on which they rest, and few will realize to what an extent iron differs from the other metals in these regards. In this volume we are about to take up the study of iron ores in their various industrial and political relations; and before doing this it seems advisable to give some consideration to certain facts relative to the metal into which these ores will ultimately be transformed This introductory discussion, brief though it must necessarily be, will serve to give some idea as to the present industrial status of the metal iron, and will also emphasize the fact that questions as to iron-ore resources are not merely of local or individual interest, but are of the greatest possible general importance.

In taking up consideration of the industrial status of iron, and its relative commercial importance among the metals, it is of course inadvisable to confine attention to the conditions in any one country, for improvements in transportation are tending toward a very broad world-market in such products. It may also be noted that the distribution of metallic ore deposits throughout the world is so irregular that much of the truth is missed if we narrow the scope of the study. Fortunately the statistical data as to metal production and prices are extensive and reasonably trustworthy, so that there will be little difficulty in taking up the question on the broadest possible basis.

Relative Tonnage Importance.—At the outset, a statement as to relative tonnage will serve as a convenient starting-point. *Pig iron now makes up* 95 *percent of the total tonnage of all kinds of metal annually produced in the world.* The exact facts on this point, as shown by the statistics for 1910, are given in the table below. The data in this table referring to production of lead, copper, zinc, tin, aluminum, nickel, silver and quicksilver are taken from the annual publication of the Metallgesellschaft of Frankfort; the gold tonnage is calculated from reports of the Director of the United States Mint; and the pig-iron tonnage is an estimate by the present writer, based on official reports of the various iron-producing countries.

WORLD'S METAL OUTPUT, 1910; TONNAGE AND VALUE

Metal	Metric tons	Total value, dollars
Pig iron	65,300,000	$979,500,000
Lead	1,139,700	74,200,000
Copper	836,900	254,850,000
Zinc	816,600	94,425,000
Tin	115,700	90,350,000
Aluminum	43,800	15,875,000
Nickel	24,500	16,325,000
Silver	7,437	135,475,000
Quicksilver	4,100	5,575,000
Gold	704	454,214,000
	68,289,441	$2,120,789,000

Relative Total Values.—The disproportion between the tonnage of iron and that of all other metals combined, as shown in the preceding table, is so great that there is no need to emphasize the fact by putting it in graphic form. But with regard to the question of total values, the comparative figures are closer

WORLD'S PRODUCTION OF METALS, IN METRIC TONS

Year	Iron	Lead	Copper	Zinc	Tin	Aluminum	Nickel	Silver	Quicksilver	Gold
1901	41,000,000	860,500	534,800	507,400	89,200	7,500	8,900	5,463	3,100	395
1902	....	882,000	553,300	545,300	96,700	7,800	8,700	5,782	4,100	446
1903	46,368,000	902,600	591,300	571,600	100,500	8,200	9,900	5,647	3,600	490
1904	....	970,300	647,900	625,400	103,100	9,300	12,000	5,503	3,800	525
1905	....	965,400	693,900	658,700	102,400	11,500	12,500	5,624	3,300	574
1906	58,650,000	984,100	720,600	702,000	104,400	14,500	14,300	5,650	3,800	609
1907	....	1,027,000	712,000	738,400	102,400	19,800	14,100	6,113	3,200	620
1908	....	1,077,100	757,800	722,100	113,300	18,600	14,600	7,004	3,300	650
1909	60,314,000	1,092,000	849,200	783,200	113,900	31,200	17,300	7,337	3,700	710
1910	65,300,000	1,139,700	836,900	816,600	115,700	43,800	20,100	7,437	3,600	704
Percent increase, 1901–10	59	33	57	61	29	484	126	36	16	79

together, so that a diagram will show the situation in this regard very satisfactorily. The accompanying diagram (Fig. 1) has accordingly been prepared to illustrate this point.

The Metals Compared, 1901–1910.—We are dealing, then, with a metal which so far as tonnage is concerned is nineteen times as important as all the other metals combined; while as regards value, even when figured in its cheapest commercial form as pig iron, it still accounts for almost half of the total value of the world's metal production. Before going further it may be best to consider for a moment a series of comparisons covering, not a single year only, but an entire decade.

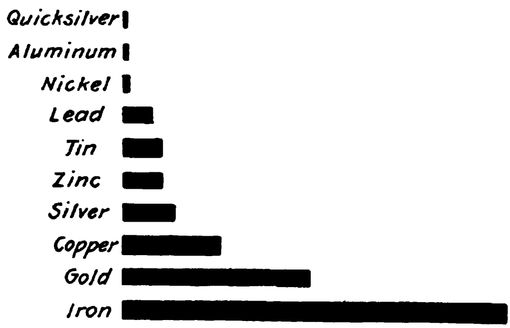


FIG. 1.—Relative values of annual output of chief commercial metals.

The table on page 3 is made up like the preceding one, the data as to the non-ferrous metals (except gold) being from the reports of the Metallgesellschaft; while the iron data are quoted either directly from the reports of Mr. J. M. Swank, or prepared by the present writer.

In order to put this comparison into more definite shape, the percentage of increase has been calculated for each metal during the nine-year period 1901–1910, and is given in the lowest line of the table. This brings out certain interesting features as regards the manner in which the various metals have responded to the great increase in general industrial and commercial activity during that period.

It will be seen, for example, that of the four leading tonnage metals, three have shown almost exactly the same rate of increase of output, while the fourth—lead—has lagged behind very noticeably. Of the five metals (excluding gold for the moment) of small tonnage, two have shown a very remarkable rate of increase, while the three others have increased at a rate very much slower than the average.

Taking the whole period and all the metals into consideration, it will be seen that the heavy tonnage metals have increased in

output at so nearly the same rate that in 1901, as in 1910, iron accounts for almost exactly 95 percent of the total metal tonnage. It might further be noted that, throughout this period, the iron-copper ratio does not change appreciably, holding in the neighborhood of 80 : 1.

Attention may profitably be turned, for a moment, to the rate of increase in the gold output, for here we get into rather close touch with a question which is often discussed on a rather vague and general basis. It will be seen that in the period 1901–1910, the world's annual output of gold increased 79 percent. Now this is not only a very large rate of increase, considered by itself, but it is obviously entirely out of line with the rate at which the more important industrial metals have increased. It would be very difficult to believe that the demand for gold for *industrial* uses has during this decade increased much more rapidly than the demand for iron, or copper or lead. But, unless we can accept such a theory the only remaining explanation is that the gold mined in excess of the actual industrial demand must operate to temporarily lower the value of gold, relative to all other commodities. It would be difficult to place any other construction on the facts of the case, as brought out incidentally by our present study of the general metal situation, but since we are not engaged in an examination of the cause of the universal rise in commodity prices, the matter can be dropped at this point.

Summary of Comparisons.—The principal facts brought out by a study of the preceding tables can now be conveniently placed in comparative form, as in the summary table below.

SUMMARY OF COMPARISONS OF VARIOUS METALS, 1910

Metal	Percentage of world's metal output by tonnage	Percentage of world's metal output by value	Selling price per ton, using as basis iron = 1
Iron	95.62 percent	46.2 percent	1
Lead	1.67 percent	3.5 percent	4
Copper	1.23 percent	12.0 percent	20
Zinc	1.19 percent	4.5 percent	8
Tin	0.17 percent	4.3 percent	52
Aluminum	0.06 percent	0.7 percent	24
Nickel	0.040 percent	0.8 percent	46
Silver	0.011 percent	6.3 percent	1,200
Quicksilver	0.006 percent	0.3 percent	90
Gold	0.001 percent	21.4 percent	40,000
	100.00 percent	100.0 percent	

This covers the main comparisons which can be made between the leading commercial metals.

Relative Natural Scarcity of Metals.—A matter of great interesa in the present connection, were it possible to secure definite date concerning it, would be the determination of the actual relativs scarcity of metals in nature. Various geologists and chemists have made investigations along this line, and though from the nature of the case precise and accurate results can not be obtained, certain broad features as to relative abundance and scarcity are brought out sharply enough.

The following table contains the data available with respect to the relative natural scarcity of most of the commercial metals. The percentages credited to aluminum, iron, nickel and manganese are derived from the most recent work of Clarke,[1] and are based upon a very large number of analyses of sedimentary and igneous rocks, made in the laboratory of the United States Geological Survey. These analyses have been compared, weighted and averaged by Dr. Clarke, and the four figures particularly quoted here may be accepted as being as close to the truth as we are likely to get in this matter. The figures for aluminum and iron, especially, are unlikely to be materially changed by any further analytical work. Those for manganese and nickel, owing to being based upon a smaller number of occurrences, are of course less firmly determined.

The figures quoted for the other metals covered by the table—zinc, lead, copper, silver and gold—are estimates made by Lindgren[2] in a recent publication, and may be taken as representing the most authoritative statement upon the relative scarcity of the rarer commercial metals.

RELATIVE NATURAL SCARCITY OF COMMERCIAL METALS

Metal	Percentage in earth's crust	Relative abundance, gold = 1
Aluminum	7.84 percent	15,680,000
Iron	4.44	8,800,000
Manganese	0.08	160,000
Nickel	0.023	46,000
Copper	0.0075	15,000
Zinc	0.0040	8,000
Lead	0.0020	4,000
Silver	0.00001	20
Gold	0.0000005	1

[1] Data of Geochemistry, Bulletin 491, U. S. Geol. Survey, pp. 32–34.

[2] Mineral Deposits, p. 14.

The figures given in the third column have been calculated from those in the second, in order to bring out more sharply some of the comparative results.

If the preceding table, and particularly its last column, be compared with tables previously given (pages 2, 5) regarding the actual output and value of the different metals, certain very remarkable disparities will at once appear. The extent and the importance of these differences are sufficient to suggest that further investigation, both by geologists and economists, would be well repaid. In the present place it is not possible to do more than call attention to their general character and bearings.

It will be best to confine attention to more important commercial metals, and compare them in turn as regards estimated natural scarcity, actual annual tonnage produced, and average price per ton. Using gold in each case as the basis of reference, the results will work out somewhat as in the following little table, in which round numbers are used for convenience.

Metal	Natural abundance	Annual output	Cheapness
Gold	1	1	1
Silver	20	10	30
Lead	4,000	1,600	10,003
Zinc	8,000	1,150	5,000
Copper	15,000	1,180	2,000
Iron	8,800,000	92,000	40,000

It can be seen at once that natural scarcity has very little to do with either the price of a metal or with the tonnage produced. Even allowing for the wide differences which exist in commercial utility of the various metals covered by this table, there are sufficient disparities to suggest that disproportionate efforts are expended in the search for certain metals, and in the mining and metallurgical difficulties encountered in placing them in commercial form. The most striking instance is gold, which seems to be produced in tonnages far larger than could be expected, while its relative commercial value is far lower than its natural scarcity would seem to justify.

The American Situation.—An interesting final comparison might deal with the place occupied by iron in the total mineral output of the United States. The United States Geological Survey has estimated that the value of the entire mineral production of the country during 1910 was somewhat over two thousand million dollars. Of this total, iron accounts for over one-fifth.

As the distribution of the total may show some facts not commonly understood, it has been summarized here as follows:

Fuels: coal, oil and natural gas	$822,453,349
Pig iron	425,115,235
Structural materials: cements, stone and clay products	362,808,130
All other metals and non-metals	393,368,155
Total value mineral production	$2,003,744,869

It will be seen that the metals, other than iron, must be of little importance in reality, though they bulk large in the popular imagination. As a matter of fact, the monetary uses of gold and the general utility of iron have combined to give a fictitious importance to the metals in general, as compared with the non-metallic mineral products.

Summary.—To summarize the situation as regards iron, then, we are dealing with a metal which the furnaces of the world are now turning out at the rate of over sixty-five million tons a year; and this annual output is increasing rapidly and steadily. When business is good, the furnaces in some distrcts will realize as much as one cent a pound for their product; when business is poor, some districts will sell their iron for one-half cent a pound, or even less. The product itself will, in either case, enter into the commerce of the world, and into the industrial progress of the race, in a way not even approached by any other metal.

Compared with this, the other metals are not seriously important as to tonnage; they are produced at larger rates of profit, and sold at far higher prices; and even a temporary scarcity in one of them simply means the use of some substitute metal. It is obvious that the metal iron could not be so much cheaper, so much more abundant in supply, and therefore so much more generally useful if it were not for natural advantages as to the extent and distribution of the ores from which it is made. In the following chapter, where the natural ores of iron are described, some space will be given to consideration of the original abundance in nature of this element; while in later chapters dealing with iron-ore deposits the methods will be noted by which this original abundance has been made available for use. It is also obvious that in view of its importance industrially and commercially, matters which seriously affect the iron industry must have a more direct effect on general prosperity than questions relating to less important industries.

PART I. THE ORIGIN OF IRON ORES.

CHAPTER II

THE GEOLOGIC AND CHEMICAL RELATIONS OF IRON

In discussing the industrial status of the metal iron, it has been seen that it is produced in enormous quantities, far surpassing in tonnage all the other metals combined; and that in spite of the great demand for it, iron is produced and sold at a very low price, far lower than the price of any other metal. It is clear enough that, even allowing for cheap and efficient processes of extraction, metallic iron could not be turned out at so many points, in such quantities and at such prices unless its ores were both extremely abundant and widely distributed over the earth's surface. This is indeed the case; and in turn we may trace back this abundance of workable iron ores to an original natural abundance of the element iron in the rocks which compose the crust of the earth and to certain chemical relations which have aided in putting a fraction of the total iron content into convenient form for extraction and utilization.

Natural Abundance of Iron.—It has been determined by Professor F. W. Clarke,[1] who has made an exhaustive study of the average composition of the earth's crustal rocks, that the element iron makes up 4.44 percent by weight of the known portion of the earth. If it were possible to form any definite idea of the composition of the central parts of the globe, it is probable that iron would take a still more prominent place as to abundance among the chemical elements. As it is, it is outranked only by oxygen, silicon and aluminum, though it is closely followed by lime. The percentages of the more common elements are as follows:

AVERAGE COMPOSITION OF THE EARTH'S CRUST (F. W. CLARKE)

Oxygen	47.17 percent	Hydrogen	0.23 percent
Silicon	28.00	Carbon	0.19
Aluminum	7.84	Phosphorus	0.11
Iron	4.44	Sulphur	0.11
Calcium	3.42	Fluorine	0.10
Potassium	2.49	Barium	0.09
Sodium	2.43	Manganese	0.08
Magnesium	2.27	Chlorine	0.06
Titanium	0.44	Strontium	0.03
		All others	0.50

[1] Bulletin 491, U. S. Geol. Survey, pp. 33–34.

Mere inspection of this table will serve to indicate the comparative abundance of the element iron, so far as the bulk composition of the earth's crust is concerned. As will be noted later, this is not the whole of the story, for if mere abundance in the crustal average were the sole basis of industrial availability, aluminum and silicon would be far more important commercially than iron.

Iron Ores and Ore Deposits.—In following out this line of investigation, it is next to be noted that the world's supply of commercial metallic iron is not procured from such widely diffused sources as the rocks of the earth's crust have, by the preceding analysis, been proven to be, but from well-localized deposits of certain definite minerals rich in iron.

Iron is a more or less important constituent of a large number of different minerals, but only a few of these are under present conditions available for use as iron ores. In a later chapter it will be possible to discuss the composition and relationships of the principal iron minerals in proper detail. Here it is only necessary to say that the bulk of our commercial iron is produced from one of four different minerals or ores. Of these three are oxides of iron, and one is a carbonate. The oxide ores are by far the more important, the carbonate being only locally serviceable when fuel conditions are satisfactory. The three oxide ores, named in the order of their commercial importance are hematite, magnetite, and brown ore (limonite).

It has also been noted above that the iron minerals, no matter how pure they might be, would be unserviceable commercially if they occurred diffused or scattered through a large mass of barren rock. In order to be commercially available, the ore minerals must occur in fairly well concentrated and localized deposits. The origin and characters of such deposits will be treated in some detail in the later chapters, but before taking up the classification and detailed discussion of the different types of iron-ore deposits, it is necessary to consider briefly the basal chemical and geologic principles and data on which any such detailed study must be founded. It may be assumed that the iron now concentrated into workable ore deposits was once contained in diffused form in the igneous rocks, and that in the course of the alteration and decay of these rocks their contained iron was freed, carried off either mechanically or in solution, and

re-deposited elsewhere. Before discussing the particular ways in which our existing iron-ore deposits were formed, it is evidently advisable to consider the form and amount in which iron occurs in the igneous rocks, the extent to which it has been carried over to form part of the normal sedimentary rocks, and the chief chemical reactions which can be relied on to aid in the transfer and deposition of the iron. These basal data will be taken up in the present section of the chapter.

The Growth of the Earth.—Many of our commercial iron deposits are of quite recent origin, but others date far back in geologic history. Throughout the discussion of ore deposits it will be necessary to refer at intervals to the conditions which have existed at earlier stages in the history of the earth and in order to make such references intelligible it will be well to summarize briefly, in the present place, the chief factors in the growth of the earth.

For our present purposes it is sufficiently accurate to assume that the earth, in the earliest stage of its history requiring consideration here, was a fused mass, approximately spherical in shape, cooling slowly from the exterior inward, and surrounded by an envelope of gases. When this cooling had progressed far enough, the earth's exterior and center solidified gradually. A surface or crust of *igneous* rocks was thus formed, while local differences in the rate of cooling caused irregularities in this surface. Combinations of the cooling gases caused the precipitation of water, in the form of rain; and with the action of the first surface water the formation of the *sedimentary* rocks was begun. The fallen rain gathered in slight depressions of the crust to form the earliest streams and rivers; and followed these courses to deeper depressions which formed the earliest seas and oceans. In its course the water, whether raindrop or stream, carried off small portions of the rocks it encountered, transporting them either mechanically or in solution, and deposited them finally as sediments. This process has continued to the present day, a steady supply of detritus being carried to the seas; and it is obvious that only the action of some counter-balancing process can prevent all the land areas being worn down to sea-level. The necessary compensatory action is afforded by the gradual depression, at intervals, of portions of the sea-bottom which have been overloaded by deposits of sediment, and the consequent

relative elevation of the land areas. The process is therefore continuous, forming a regular three-phase cycle, the phases being (1) erosion of high lands by running water; (2) deposition of the resulting detritus on the sea-bottom; (3) overloading and consequent depression of parts of the sea-bottom; with a corresponding relative elevation of the land, and the recommencement of erosion. At intervals in the earth's history these regular cyclical changes have been aided or retarded by less regular occurrences. At some periods, for example, igneous activity has been more pronounced, so that masses of fused rock have been forced up from the interior to cool at or near the surface; heat and pressure, long continued, have caused great physical and chemical changes in deeply buried rock masses; minor movements in the earth's crust have caused folds, faults and joints in the rock beds; and temperature changes have altered conditions in the different areas. All of these phenomena have affected the arrangement and composition of the rocks, and have aided in such rearrangement of their mineral contents as have finally produced our existing ore deposits.

The Relative Age of Rocks.—Whenever the study of any particular ore deposit is taken up, it will be found that the geologic factors which have just been summarized have a very immediate and practical bearing upon the problem. The chief points which must inevitably be considered relate to the age and character of the rocks associated with the ores, and to their distribution and relative attitude.

The geologist, confronted with a finished product—a given tract of country—endeavors to work out its history. Usually the first step in this direction will be to map the areas covered by different kinds of rock, but along with this areal mapping he must carry on studies to determine the relative age of the various rock formations which occur within the limits of the tract under consideration. In doing this the following criteria are of most service.

(*a*) *Superposition.*—Since sedimentary rocks are surface deposits, it is obvious that of two series of sedimentary rocks, the overlying series must be the younger, provided that no serious earth movements have altered their relative position since they were deposited.

(*b*) *Contained Fragments.*—If one rock formation contains

pebbles or other fragments of material evidently derived from another formation, the fragment-containing bed must have been formed after the other had been deposited.

(c) *Contained Fossils.*—This criterion, which is usually the most exact and positive of all, is not immediately evident like the two preceding. In the progress of geologic science, it has been ascertained that rocks of certain age are characterized by certain assemblages of fossil remains. Life was, so far as known, existent before the formation of our earliest sedimentary rocks. Through the following ages, however, it has greatly changed in type; and this gradual evolution in living organisms aids in determining the relative ages of the rocks in which their remains are now found enclosed. Comparison of the fossils found in rocks of the particular area under study, with those occurring in some area where the geologic succession is already known, will therefore serve to fix the relative position and age of the new rock series.

Geologic Chronology.—By the careful application of the criteria briefly described in the preceding section, a fairly complete geologic chronology has been gradually worked out to cover the whole extent of earth history. For convenience of reference and comparison, all of geologic time is primarily divided into twelve *periods*, which in turn are subdivided into *epochs*. Still more minute subdivisions are *stages*, while the final unit of division is the *formation*.

This system of subdivision gives a series of time intervals which, taken together, cover all geologic history. The names of the periods are given later in order downward from the most recent (Quaternary) to the earliest (Archæan). In a few cases the subdivisions into epochs are also given.

To the engineer the determination of the exact geologic age of the rocks of any given district is rarely a matter of importance, except in so far as geologic age may affect the character of the mineral products which the rocks may contain. In any particular area, a relation between geologic age and character of mineral product is, of course, quite common. A case in point is the red or fossil iron ore, so important to the iron industry of the southern United States. This ore occurs in the eastern United States in rocks of Clinton age, and the presence or absence of the ore on any particular property can therefore be inferred on

purely geologic grounds. In Luxembourg, however, an entirely similar ore occurs in rocks of much later age—so that it is evident that such a generalization is safe only within rather close geographic limits.

	Period	Epoch
Cenozoic	Quaternary	Recent
		Pleistocene
	Tertiary	Pliocene
		Miocene
		Oligocene
		Eocene
Mesozoic	Cretaceous	
	Jurassic	
	Triassic	
Paleozoic	Carboniferous	Permian
		Pennsylvanian or Coal Measures
		Mississippian or Subcarboniferous
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Pre-Cambrian	Algonkian	
	Archæan	

Whatever may be the facts as to age, there is still to be considered the matter of rock classification, so that it may be determined what kinds of rocks are associated with the ores. The classification will depend, first upon the mode of origin of the rock, and second upon its composition. So far as origin is concerned, rocks are divided into *igneous* and *sedimentary*. Iron, in one form or another, is almost universally present in the rocks of both groups.

Igneous Rocks.—The igneous rocks are those which have been formed by the cooling of fused material. The original crust of the earth was of course formed entirely of igneous rocks, but it is highly improbable that any of this original crust is now exposed at the earth's surface. The igneous rocks with which we actually have to deal are of later origin, being derived from molten material which at different periods has been forced up into and through other rocks. In most cases this molten rock did not reach the surface while fused, but cooled and solidified slowly while still covered by thick masses of overlying rock, and is now

exposed to view owing to the erosion and removal of this covering.

When molten masses cooled in large bodies, or at considerable depths below the surface, the solidification was in consequence so slow as to permit the formation of large crystals of the different constituent minerals. Our ordinary granites are good examples of such slowly cooled products. But when the local supply of molten material was small, or when solidification took place at or near the surface, the cooling was so rapid that the resulting rocks are made up of very small mineral crystals, often enveloped in a glassy matrix; while a still more rapid cooling might result in a rock having an entirely glassy structure, absolutely free from crystals. If, as happened in places, the igneous material was introduced into the air or into water while still molten (as in volcanic action), the result was the formation of porous products—volcanic ash, pumice, etc.

Perhaps the conditions above outlined may be more clearly realized if they are compared with a parallel series of perfectly familiar phenomena which occur every day in the handling of slag at blast furnaces. If furnace slag is cooled with very great slowness, it will develop crystals of various silicate minerals. On the other hand, the slag as it usually cools on a slag bank has an entirely glassy texture. Finally, if the molten slag is led into water, or if a current of steam, air or water is injected into the stream of molten slag, the slag will cool or granulate so suddenly as to assume a porous texture, exactly like a volcanic ash.

Since all igneous rocks are formed by direct cooling from a state of fusion, it is obvious that none of them can show any true bedding, for that is a characteristic of materials deposited by or in water. The differences in structure can not be due to the sorting influence of water, but must be entirely due to the varying conditions under which they cooled, or to the effects of later earth movements on the cooled mass. Considering igneous rocks in general, two different types of structure may exist.

1. In an igneous rock which has solidified quietly from a fused state, and which has not been later subjected to severe external stresses, the constituent mineral crystals are irregularly arranged, showing no trace of parallel banding or lamination. Such rocks are termed *massive* igneous rocks.

2. If, however, rocks of this same origin and composition had

or were sediments [illegible] originally

been subjected, either during or after their cooling, to external pressure, a laminated structure might have been developed. When this has occurred under favorable conditions the constituent minerals may be arranged in more or less definite alternating bands; while when the lamination is less completely developed the mineral crystals will merely be arranged with their longer axes in the same direction. In either case the rock is termed a *gneiss*.

The igneous rocks consist largely of silica—from 35 to 80 percent—with lesser amounts of alumina. According to their class they may also contain more or less iron oxides, lime, magnesia, potash, and soda. They all contain iron in some form, though in greatly varying amounts.

Prof. F. W. Clarke[1] has published the following analysis as representing the average composition of the igneous rocks. It is based upon several thousand complete and partial analyses, made in the laboratory of the United States Geological Survey, and covering igneous rocks of widely different type and locality.

AVERAGE COMPOSITION OF IGNEOUS ROCKS

Silica	59.93 percent	Barium oxide	0.11 percent
Alumina	14.97	Fluorine	0.10
Ferrous oxide	3.42	Manganese oxide	0.10
Ferric oxide	2.58	Chlorine	0.06
Lime	4.78	Chromium oxide	0.05
Magnesia	3.85	Strontium oxide	0.04
Soda	3.40	Zirconium oxide	0.03
Potash	2.99	Nickel oxide	0.03
Water	1.94	Vanadium oxide	0.02
Titanium oxide	0.74	Lithium oxide	0.01
Carbon dioxide	0.48		
Phosphorus pentoxide	0.26		100.00
Sulphur	0.11		

Inspection of the preceding table will show that the two iron oxides together make up exactly 6 percent of the total mass of igneous rocks. This is equivalent to 4.47 percent of metallic iron.

As to the form in which the iron occurs in these igneous rocks, it may be said that though it is present occasionally in the actual form of one of the iron-oxide minerals (magnetite, hematite), or as iron sulphide, it is present far more commonly as an iron silicate mineral, or as one constituent of a more complex silicate.

[1] Bulletin 491, U. S. Geol. Survey, p. 27.

Sedimentary Rocks.—The *sedimentary* rocks are those derived from the decay of pre-existing strata, the material so obtained being carried by water in suspension or solution to some point where it is re-deposited as a bed of sand, clay or limestone. Subsequently this loosely deposited material may become consolidated and hardened by pressure or other agencies, the result being the formation of sandstones, shales or slates from the original beds of sand and clay.

A convenient working classification of the sedimentary rocks, satisfactory enough for our present purposes, is that following. It will be seen that these rocks can be divided into three fairly distinct groups, the basis for the division, as given below, being partly chemical and partly physical. In later analyses the sharpness of the chemical distinctions between the groups will be more strikingly illustrated.

(1) *Siliceous* sediments; composed of grains or pebbles, usually of quartz—*sandstones, conglomerates.*

(2) *Argillaceous* sediments; composed of clayey materials—*shales, slates.*

(3) *Calcareous* sediments; composed largely or entirely of carbonate of lime, with or without carbonate of magnesia—*limestones, dolomites, marbles.*

It may here be noted that the geologist, in speaking of *rocks*, includes not only the hard materials commonly known by that name but also the soft, unconsolidated phases of these same materials, i.e., sands, gravels, clays, marls, etc. This introduces a cross classification, based on the degree of consolidation of the material, as indicated in the little table following:

Kind of rock	Degree of consolidation		
	Entirely unconsolidated	Normally consolidated	Metamorphosed, extremely consolidated
Siliceous rocks	Sand, gravel	Sandstones, conglomerates	Quartzites
Argillaceous rocks	Clays	Shales	Slates, schists
Calcareous rocks	Marls	Limestones	Marbles

With the exception of a few relatively unimportant instances where ice or wind have played some part in the deposition of rocks, all of the sedimentary rocks have been deposited in bodies of water. In most cases water has been both the transporting and the depositing agent, but chemical and organic agencies

have in many instances affected the result. The most characteristic feature about sedimentary rocks, as distinguished from igneous rocks, is the fact that the sediments are almost invariably divided into beds or layers. This characteristic feature arises from the fact that sedimentation is never absolutely continuous and uniform. Variations in the water level, in the direction of currents, or in composition of the particles of material carried by the water in suspension—all of these have an influence in this matter. Even slight changes in the composition of the deposit are apt to be reflected by differences of color, texture, etc., which suffice to mark out the bedding planes of the resulting rock.

The following table, also quoted from F. W. Clarke,[1] shows the extent to which iron has become distributed throughout the mass of the normal sedimentary rocks. In these rocks the iron is usually present as carbonate, sulphide or oxide; though iron silicates also occur in some of the sediments.

AVERAGE COMPOSITION OF SEDIMENTARY ROCKS (F. W. CLARKE)

	Shales	Sandstones	Limestones
Silica	58.10	78.33	5.19
Alumina	15.40	4.77	0.81
Ferric oxide	4.02	1.07	0.54
Ferrous oxide	2.45	0.30	....
Lime	3.11	5.50	42.57
Magnesia	2.44	1.16	7.89
Soda	1.30	0.45	0.05
Potash	3.24	1.31	0.33
Water	5.00	1.63	0.77
Carbon dioxide	2.63	5.03	41.54
Titanium oxide	0.65	0.25	0.06
Phosphorus pentoxide	0.17	0.08	0.04
Sulphur	....	....	0.09
Sulphur trioxide	0.64	0.07	0.05
Barium oxide	0.05	0.05	....
Manganese oxide	....	....	0.05
Chlorine	....	....	0.02

Structure of Rock Masses.—If rocks, either igneous or sedimentary, were unchanged in composition or attitude from the condition in which they were originally formed, there would have been little opportunity for rearrangement and concentra-

[1] Bulletin 491, U. S. Geol. Survey, p. 32.

tion of their mineral contents; and under such conditions very few of our existing iron-ore deposits would ever have been formed. As a matter of fact, however, great changes in these regards have been experienced by most of the rocks now exposed in the earth's crust as the result of long-continued heat and pressure, aided by earth movements. The changes in attitude and structure have been effective not only in permitting or aiding the natural concentration of the diffused iron into ore deposits, but in rendering such deposits more or less accessible after their formation. Particular instances of these effects will be found in the discussions of the various ore districts, in later chapters of this work. Here the main types of structural change may be briefly noted for convenience in further reading.

The beds of sedimentary rocks, having been formed for the most part by deposition on the gently sloping bottoms of bodies of water, would naturally have a horizontal or nearly horizontal attitude at the time of their formation. But during the numerous elevations and depressions of the land which have occurred since their deposition, this original horizontality of bedding was in many cases destroyed, so that now we may find sedimentary rocks whose beds are inclined at all angles to the horizontal. This is particularly true in the Appalachian, Lake Superior, Rocky Mountain, and Pacific Coast regions, where horizontal strata are the exception rather than the rule. In the central United States, however, most of the rocks still lie almost or quite horizontal, an inclination of over five degrees being distinctly uncommon in the States of the Mississippi basin.

In the course of earth movements, folds and flexures of various types are developed in beds of rock which may previously have been horizontal. If the movement simply elevates or depresses one side of an area, so that as a result the rocks everywhere dip in the same direction, the resulting attitude of the rocks is called a *monocline*. If, however, compressive or tensile stresses accompany the uplift or depression, a complete fold of some sort will be formed.

When a complete fold is presented for observation, it may be either a *syncline* or trough, in which the strata on both sides dip toward the axis of the fold; or an *anticline* or arch, in which the strata on both sides dip away from the axis.

When, in the course of earth movements, the strata subjected

to stress are too rigid to yield by folding, or when the stress is applied too rapidly, they will yield by fracture. Such fractures result in the formation of a *fault*, which may be considered simply as a break in the strata accompanied by elevation or depression of the beds on one side of the fault plane. On a large or small scale, faulting is a very common phenomenon, particularly in regions of intense folding. It is a matter of peculiar importance to the mining engineer, since the existence of faults in a district complicates the underground structure, and renders it difficult to follow out a mineral deposit affected by faulting.

So far the structural features, such as folds and faults, have been considered purely as physical phenomena, but were this their only interest it would not have been necessary to refer to them in this chapter. Their importance in the present connection arises from the facts that these structural factors have in many instances had a direct effect upon the occurrence, the form, or the commercial availability of iron-ore deposits, as will be seen later during discussion of actual deposits of various types. In this work they have been aided by certain chemical properties of the iron compounds, which may now be briefly noted.

The Two Series of Iron Compounds.—The extent and importance of workable deposits of iron ore is not due entirely to the fact that the element iron is both abundant and widely distributed in the rocks of the earth's crust. If those were the only factors in the case we could reasonably expect to find that aluminum ores were more common than iron ores, for alumina makes up about 15 percent of the crustal rocks as compared with the 6 percent of iron oxide. But as a matter of fact, aluminum ores are very scarce as compared with iron ores.

Much of the extent of our iron deposits is due to the fact that this element forms two series of compounds, that these series are interchangeable under certain conditions, and that they have very different chemical and physical properties. The two series are known as *ferrous* and *ferric* compounds respectively.

Ferrous oxide is composed of one atom of oxygen united to one atom of iron, and its chemical formula is therefore FeO. When combined with other elements, ferrous oxide yields a long series of ferrous compounds. Of these, the most important from our present viewpoint are ferrous carbonate ($FeCO_3$), ferrous di-

sulphide (FeS_2), ferrous sulphate ($FeSO_4$) and the various ferrous silicates. The ferrous compounds agree in being relatively unstable and usually soluble in natural waters.

Ferric oxide is composed of two atoms of iron united with three atoms of oxygen, and its chemical formula is therefore Fe_2O_3. None of the other ferric compounds are of great importance in the present connection. Ferric oxde is relatively stable, and practically insoluble in ordinary surface waters.

CHAPTER III

THE IRON MINERALS AND THEIR RELATIONSHIPS

In discussing the geologic relations of iron it was noted that the metallic iron used in the world is not derived from such widely diffused sources as ordinary rocks, but from certain minerals particularly rich in iron; and it was also noted that only a few such minerals were commercially used. Before taking up the formation of iron-ore deposits, it will be well to consider the minerals which are of most importance in this connection.

A vast number of mineral species exist which contain more or less iron; but in most cases either the iron percentage is too small for industrial use, or else the mineral itself is too rare to be used as an ore. For example, natural metallic iron, or "native iron" does occur as a mineral, but it is so scarce and unimportant as not to require more than mention here as a mineralogical curiosity. If at any time large deposits of it were struck, it would be a valuable ore because of its purity. On the other hand, many of the iron silicate minerals occur in vast quantities, and are therefore available enough so far as tonnage is concerned, but their percentage of iron is so low compared with their silica content that they are at present unavailable for use as ores. So far as the commercial manufacture of iron is concerned, therefore, attention can be concentrated on a surprisingly small number of economically available iron-bearing minerals.

The Grouping of the Iron Minerals.—The principal iron-bearing minerals which are now used as ores of that metal fall, when considered from the chemical point of view, into two classes —*oxides* and *carbonates*. Of these two groups, the oxides are by far the more important industrially. In addition, some consideration must be given to two other groups—the iron *silicates* and the iron *sulphides*. Silicate ores are now used at one or two European smelting centers, and under certain conditions may ultimately come into limited use elsewhere. Iron sulphides, though not serviceable as ores naturally, are of indirect interest and importance as sources of iron both in manufacturing processes and in nature.

The groups of industrially important iron minerals noted above may be taken up in some detail, but it seems advisable to re-arrange the grouping somewhat in order to give proper weight to the relative importance of the iron oxide group. This is readily separable into three sub-groups, which are defined not only by their chemical characteristics but by differences in their industrial value, and by great differences in the origin and associations of the deposits in which they occur. These sub-groups, with the other main groups, have been noted in the following table, which summarizes the classification which will be used in the present chapter:

CHIEF IRON MINERALS

A. Iron oxides:	
Ferro-ferric oxides.	1. *Magnetite group.*
Ferric oxides:	
Anhydrous.	2. *Hematite group.*
Hydrous.	3. *Brown ore group.*
B. Iron carbonates.	4. *Carbonate group.*
C. Iron silicates.	5. *Silicate group.*
D. Iron sulphides.	6. *Sulphide group.*

Each of these groups can now be discussed, in the order in which they are named in the preceding summary.

1. *Magnetite Group.*—The typical member of this group is the mineral *magnetite,* though several closely related species are of some economic interest Magnetite has for its chemical formula Fe_3O_4, corresponding to the composition metallic iron 72.4 percent oxygen, 27.6 percent. Pure magnetite is therefore the richest known ore of iron. This is due to the fact that part of its iron is in the ferrous state, and requires less oxygen to balance it than does the iron of the pure ferric oxides.

The constitution of the magnetic or ferro-ferric oxide can perhaps be most clearly understood if it be taken as an equal molecular mixture of ferrous oxide and ferric oxide, as in the following equation:

$$\underset{\substack{\text{Magnetic}\\ \text{oxide}}}{Fe_3O_4} = \underset{\substack{\text{Ferrous}\\ \text{oxide}}}{FeO} + \underset{\substack{\text{Ferric}\\ \text{oxide}}}{F_2O_3}$$

If we were at present dealing with the origin of the magnetic ores, it would be desirable to go further into this matter, for the above equation does not fully represent all the facts in the case, but it will be sufficiently precise for all our present purposes.

Magnetite occurs most commonly as a massive mineral, steel-gray to black in color, and with a specific gravity in the neighborhood of 5.0. Deposits of magnetite are almost invariably found in close association with igneous or highly metamorphosed rocks. When associated with crystalline limestones or with the acid igneous rocks the ore is commonly free from other metals; so that simple separation from the country rock or gangue will give a satisfactory product. But when magnetite occurs associated with basic igneous rocks, it is apt to have either mixed with it physically, or combined chemically, oxides of chromium or titanium. In these cases, though magnetic separation removes all the non-metallic material, the product will still carry much or all of the metallic impurities.

All of the magnetites possess magnetic properties, though in very variable degree and intensity. Occasionally, as in the natural lodestone of Arkansas and other localities, the ore is so intensely magnetic as to attract and hold, with considerable strength, small iron or steel articles which come within its sphere of action. Ordinarily, however, a magnetite ore will not act so positively, but it will attract the compass needle, and its small grains or fragments will be readily attracted by other magnets. This property is put to two industrial uses. The effect on the compass needle aids in determining the presence, and to some extent the size and form, of magnetite ore bodies below the ground surface; and has been developed into a very interesting prospecting method, for ores of this type. The attractability of the ore, on the other hand, is made use of in all the methods of magnetic concentration which will be referred to in the chapter dealing with concentrating processes.

2. *Hematite Group.*—The mineral hematite is composed of ferric oxide, its chemical formula being Fe_2O_3, corresponding to a composition metallic iron 70 per cent. and oxygen 30 per cent. It differs from magnetite in not containing any ferrous iron, and from the brown ores next to be discussed in being entirely anhydrous or free from combined water.

Hematite is by far the most important ore of iron on all the continents, and occurs in many varieties of form, richness and geologic association. According to the characteristics of the particular variety in hand it may be termed red hematite, specular hematite, oolitic hematite, fossil ore, etc. The hard, metallic

or specular varieties are usually found, like magnetite, associated with either igneous rocks or with very highly metamorphosed sediments. The red or fossil ores of Canada and the eastern United States, however, are associated with normal sedimentary rocks.

3. *Limonite or Brown Ore Group.*—The iron minerals here grouped together as brown ores are all hydrous ferric oxides. They agree with hematite in the fact that their iron is in the ferric form, but differ because the brown ores all contain more or less chemically combined water, while pure hematite is entirely anhydrous.

Among themselves, the different minerals here grouped as brown ores differ in the amount of the water which is chemically combined with their iron oxide. With regard to this factor, the different brown ores make up a perfect series, ranging from an almost anhydrous ore to one containing over 25 percent of combined water. The minerals which make up this series have been given the names turgite, goethite, limonite, xanthosiderite and limnite, in the order of their progressive increase in water content.

The relation between these various iron oxide minerals is best brought out if the formulas be rewritten so as to give a constant iron factor. This has accordingly been done in the table below.

Name of mineral	Chemical formula	Composition	
		Iron oxide	Water
Hematite	$2\ Fe_2O_3,\ 0\ H_2O$	100 percent	0 percent
Turgite	$2\ Fe_2O_3,\ 1\ H_2O$	94.7 percent	5.3 percent
Goethite	$2\ Fe_2O_3,\ 2\ H_2O$	89.9 percent	10.1 percent
Limonite	$2\ Fe_2O_3,\ 3\ H_2O$	85.5 percent	14.5 percent
Xanthosiderite	$2\ Fe_2O_3,\ 4\ H_2O$	81.6 percent	18.4 percent
Limnite	$2\ Fe_2O_3,\ 6\ H_2O$	74.7 percent	25.3 percent

From this table it will be seen that the six minerals in question make up a perfect series with respect to their percentages of combined water, beginning with the anhydrous oxide hematite and showing gradually increased hydration to limnite at the other end of the series.

In the above table the anhydrous ore—hematite proper—has been included in order to complete the comparison. In ordinary usage the five hydrous oxides are called indiscriminately brown ore, brown hematite or limonite. There is no possible objection

to the use of either of the first two of these terms, but to extend the use of the term limonite to cover the entire group, when it properly applies only to one mineral of that group, is simply to invite confusion. In the present volume the term limonite will be used, when at all, in its proper and restricted sense, referring to the mineral with the formula $2Fe_2O_3$; $3H_2O$. When, on the other hand, hydrous iron oxides in general are referred to, they will be called brown iron ores or simply brown ores.

4. *Iron Carbonate Group.*—The mineral called siderite or iron carbonate has the formula $FeCO_3$, which is equivalent to about 48.3 percent metallic iron. Part of the iron, however, is often replaced by other basic elements, so that in nature we find several closely graded series of minerals from the pure iron carbonate, through iron-lime carbonates, iron-manganese carbonates or iron-magnesia carbonates, to the other extremes where the lime, magnesia or manganese predominates or the iron is entirely absent.

The present chief interest of this complex group of carbonates arises from the fact that in many cases the formation of a deposit of iron carbonate was the first or an important stage in the origin of a deposit of brown ore. Iron carbonate itself is not at at present an important ore for the American iron industry, though it is still the source of supply for one of the leading English iron-making districts.

5. *The Iron Silicate Group.*—A very large number of silicate minerals contain iron, in greater or lesser percentages. Under ordinary conditions, however, the iron content is not sufficiently high to repay smelting, because of the large percentage of silica which must be fluxed. A few of these iron silicates, however, are of sufficient interest to merit a brief note. In central Bohemia and Thuringia, for example, two iron silicates—*chamosite* and *thuringite*—have been worked as commercial ores, while the present writer has run some experimental pig-metal from another silicate —*glauconite*—in the course of developing a potash recovery process. Analyses of the three silicates which have been mentioned are as follows, those of chamosite and thuringite being quoted from Beck.

It will be noted that all three of these silicate ores are aluminous and hydrated. It might further be said, though not shown by the analyses above, that all of them are high in phosphorus.

ANALYSES OF IRON SILICATES USED AS ORES

	Thuringite	Chamosite	Glauconite
Silica	22.61	18.63	46.03
Alumina	16.80	8.48	7.86
Ferrous oxide	33.10	45.13	25.23
Ferric oxide	15.43	3.73	
Combined water	10.60	6.44	8.40

Except under special conditions, it is of course obvious that they are of no serious commercial importance.

6. *The Iron Sulphide Group.*—Two different sulphides of iron occur as natural minerals. These are respectively:

a. Pyrite = iron disulphide = iron 46.7 percent, sulphur 53.3 percent.

b. Pyrrhotite = iron sulphide = iron 60.5 percent, sulphur 39.5 percent.

Of these two sulphides of iron, pyrite is the commoner, but both occur in large deposits and both are of importance in the present connection. Owing to the large sulphur content, neither of the iron sulphides is ever worked primarily as a source of iron, being regarded rather as ores of sulphur. But when the sulphur has been driven off by roasting, the residual material is an iron oxide; and this residuum, known as blue billy, is occasionally utilized "purple ore" as an iron ore. Long weathering has a similar result, a "gossan" of brown ore being thus formed naturally along the weathered outcrop of pyrite deposits.

SUMMARY OF COMPOSITION OF PRINCIPAL IRON MINERALS

Name	Composition					
	Chemical formula	Metallic iron (Fe)	Sulphur (S)	Carbon dioxide (CO_2)	Oxygen (O)	Water (H_2O)
Magnetite	Fe_3O_4	72.4	....	....	27.6	....
Hematite	Fe_2Q_3	70.0	....	....	30.0	....
Turgite	$2\ Fe_2O_3,\ H_2O$	66.2	....	....	28.5	5.3
Goethite	$Fe_2O_3,\ H_2O$	62.9	....	....	27.0	10.1
Limonite	$2Fe_2O_3,3H_2O$	59.8	....	....	25.7	14.5
Xanthosiderite	$Fe_2O_3,\ 2H_2O$	57.1	....	....	24.5	18.4
Limnite	$Fe_2O_3,\ 3H_2O$	52.3	....	....	22.4	25.3
Siderite	$FeCO_3$	48.2	....	37.9	13.9	....
Pyrrhotite	FeS	60.5	39.5	....	....	....
Pyrite	FeS_2	46.7	53.3	....	....	....

It will be seen later that the iron sulphides are of peculiar interest in a study of the origin of brown ore deposits, and that both directly and indirectly they have contributed to the formation of many of these deposits.

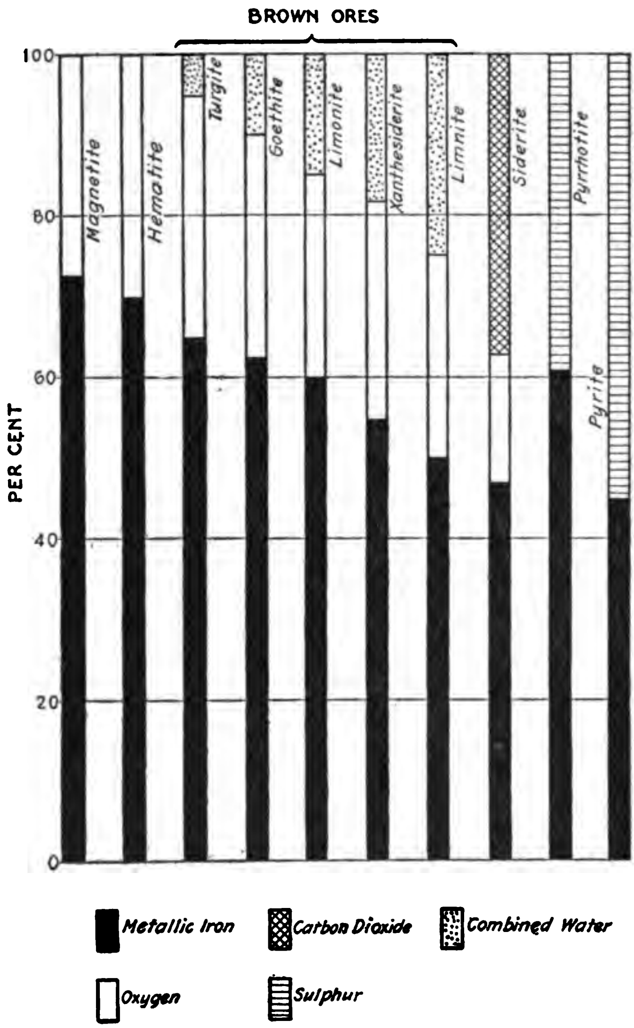


Fig. 2.—Chemical composition of the iron-ore minerals.

Chemical Relationships of the Iron Minerals.—The facts as to the chemical composition of the various iron-bearing minerals which have been noted in preceding paragraphs can best be comprehended when summarized as in the table on page 27.

Even a casual inspection of the preceding table will suffice to prove that the iron ores form a group which shows little complexity of composition. All of the important iron-bearing minerals are simple compunds of iron with oxygen, sulphur, carbon dioxide and water respectively. Iron itself, as has been pointed out in an earlier section of this chapter, is one of the most abundant of the elements; and the other constituents which we now find united with iron to form the commercial iron ores are also extremely abundant.

These facts immediately become suggestive when looked at from another viewpoint. In considering the natural processes now in action on the earth it is obvious that the growth and decay of organisms, the chemical and physical action of surface and underground waters, and the resultant weathering and decomposition of minerals and rocks are widespread in their scope, continuous in their action, and powerful in their cumulative effects. Now, among these powerful agencies, there are available different forces which may make an iron mineral soluble or may cause its precipitation; which may leach off its sulphur or remove its carbon dioxide; which may decrease or increase its percentage of oxygen or of water. The chemical elements involved in the transformations are few in number and very common; the forces involved are simple, but constant in their activity; while the time available has been sufficient to permit the production of remarkable total effects.

Relative Productive Importance of the Different Ores.—Detailed statistics on the production of the various types of iron ore in the different states will be presented in a later chapter of this volume. In the present place it is sufficient to introduce the following table, which covers the production of the various types in the United States in 1880 and in the years 1889 to 1912 inclusive.

Of the data used in the above table, it may be said that the figures for 1880 are those reported by the Tenth Census, reduced to long tons. The figures for 1889 and later years are taken from the volume Mineral Resources of the United States published annually by the United States Geological Survey.

It will be seen on examination of this table that in 1912 the hematite ores accounted for practically 90 percent of the total American output; while the brown ores and magnetites contrib-

uted each about 5 percent of the total. The carbonate production was a negligible percentage.

PRODUCTION OF KINDS OF IRON ORE IN THE UNITED STATES, 1880–1912, IN LONG TONS

Year	Hematite	Brown ore	Magnetite	Carbonate	Total
1880........	2,243,993	1,918,622	2,134,276	823,471	7,120,362
1889........	9,056,288	2,523,087	2,506,415	432,251	14,518,041
1890........	10,527,650	2,559,938	2,570,838	377,617	16,036,043
1891........	9,327,398	2,757,564	2,317,108	189,108	14,591,178
1892........	11,646,619	2,485,101	1,971,965	192,981	16,296,666
1893........	8,272,637	1,849,272	1,330,886	134,834	11,587,629
1894........	9,347,434	1,472,748	972,219	87,278	11,879,679
1895........	12,513,995	2,102,358	1,268,222	73,039	15,957,614
1896........	12,576,288	2,126,212	1,211,526	91,423	16,005,449
1897........	14,413,318	1,961,954	1,059,479	83,295	17,518,046
1898........	16,150,684	1,989,681	1,237,978	55,373	19,433,716
1899........	20,004,399	2,869,785	1,727,430	81,559	24,683,173
1900........	22,708,274	3,231,089	1,537,551	76,247	27,553,161
1901........	24,006,025	3,016,715	1,813,076	51,663	28,887,479
1902........	30,532,149	3,305,484	1,688,860	27,642	35,554,135
1903........	30,328,654	3,080,399	1,575,422	34,833	35,019,308
1904........	23,839,477	2,146,795	1,638,846	19,212	27,644,330
1905........	37,567,055	2,546,662	2,390,417	21,999	42,526,133
1906........	42,481,375	2,781,063	2,469,294	17,996	47,749,728
1907........	46,060,486	2,957,477	2,679,067	23,589	51,720,619
1908........	31,788,564	2,620,390	1,547,797	26,585	35,983,336
1909........	46,208,640	2,839,265	2,229,839	16,527	51,294,271
1910........	51,367,007	2,993,744	2,631,835	22,320	57,014,906
1911........	39,626,224	2,032,094	2,202,527	15,707	43,876,552
1912........	51,345,782	1,614,486	2,179,533	10,346	55,150,147

CHAPTER IV

THE FORMATION OF IRON ORE DEPOSITS

In the present chapter an attempt will be made to present the more important facts relative to the occurrence of deposits of iron ores, and to discuss briefly the various theories of origin which have been based upon the observed facts. In doing this, special attention will be paid to such phases of the matter as have direct bearing on the examination and commercial development of iron ore deposits of the types which are of serious industrial importance. On the other hand, the reader will fail to find the usual detailed descriptions of the formation of ore deposits of certain types which yield more in the class-room than in the furnace.

As a lengthy discussion of controverted questions would obviously be out of place in such a summary as can be presented here, the chapter must in part tend to become merely an expression of the writer's personal views on debatable points. But, as against this disadvantage, this method of treatment will at any rate secure consistency throughout, which is an advantage to the reader; and if the writer's statements or opinions are found to differ widely in some cases from accepted tradition, they have at least the merit of being based on a rather extensive experience with various types of iron-ore deposits.

Definition of Ore and Ore-deposit.—An *ore* is a mineral, or association of minerals, from which a metal can be profitably extracted under existing technical conditions.

The ore may be a single mineral, as in most iron deposits; or it may be a mass of closely associated minerals. It must, however, contain metal in such quantities and relations that there are no technical difficulties in the way of profitable extraction of the metal. For example, a mass of clay containing 10 percent of iron oxide, scattered through it in fragments, may very well be a good iron ore; but a mass of rock containing 20 or 30 percent of an iron silicate mineral would be commercially and technically unavailable as an ore under present conditions. It can be seen that

with the advance of technical knowledge, with the increasing improvement of technical processes and appliances, and with the growing scarcity of the higher grade ores of all the metals, coming generations are likely to use the term *ore* in a broader sense than we can apply it at present.

For our present purposes it will be convenient and sufficiently accurate to define an ore deposit as

A mass of ore, or ore-bearing material, large enough to be considered commercially workable, and whose grade, either without or after concentration, will repay handling.

All of the qualifications which have been introduced into the preceding definition are necessary, particularly in the case of deposits of iron ore. In the case of most brown-ore deposits, for example, we are not dealing directly with a mass of iron mineral, but with a body of clay or sand containing scattered grains or fragments of an iron mineral. In this case concentration is a very essential element in the problem.

The restrictions as to size and grade are equally necessary. It would be foolish to insist on applying the term ore deposit to an isolated mass, a few pounds or tons in weight, even of a high-grade ore. On the other hand, it would be equally unjustifiable to apply the term to a large body of material, like the Alabama Clinton "Big Seam" in part of its extent, carrying 10 to 20 percent iron, and not susceptible of commercial use.

Of the terms which are frequently used to describe workable masses of iron ore, *ore-deposit* is by far the most serviceable for general descriptive use, for it carries with it absolutely no implication as to the size, shape, age, grade or origin of the mass to which it may be applied. The term *ore-body* is just as free from implications as to origin, shape, etc., but it is not ordinarily used in quite so general fashion. We can, for example, very properly speak in a perfectly general way of the Clinton ore-*deposits*, or the Oriskany ore-*deposits;* but we would hardly speak of Clinton or Oriskany ore-*bodies* except in reference to certain specific masses.

The terms *bed* and *vein* are of much more limited utility, for when properly used each of these terms carries with it certain very definite implications as to the origin and usually as to the general shape or attitude of the mass of ore to which it is applied. In colloquial usage this distinction is often lost sight of, and the

terms are used interchangeably. It might be added that, in the western United States as least, this confusion in meaning has in part the sanction of high judicial authority. As to the proper usage of the terms *bed* and *vein*, reference should be made to the sections on the origin of iron ores, found later in this volume.

In some parts of the South, the term *ore-bank* is applied to ore deposits, more particularly to deposits of brown ore, manganese ores and bauxite. Properly, it can be applied to worked deposits of the type in which those ores usually occur, but it has no particular general value, and is rarely, if ever, applied to undeveloped deposits.

The Practical Bearing of Theories of Origin.—In a preceding paragraph the writer has suggested that in his opinion the study of methods of origin is of direct practical importance. The need for such a declaration of faith is obvious enough, when an official report by an exceptionally able geologist can, in discussing certain brown-ore deposits, summarize another view in the following despairing words: "Surface indications are thoroughly unreliable, and those most experienced in working such deposits are practically unanimous in the opinion that no deposit can be safely estimated until every ton of the ore has been mined."

If this were indeed the case with iron deposits in general, there would be little reason for the mining engineer to pay any consideration to the possible origin of the ore deposit which he was developing, for a theory which can not be safely used as a basis for practical work is merely an interesting toy. In the writer's opinion, however, such a pessimistic view of the case is really not justified at the present day, and he feels that, even in the case of brown ores, "those most experienced in working such deposits" are not quite so hopeless as the quotation might imply. On the contrary, it should be most clearly and thoroughly understood that unless the mode of origin of an ore deposit is fairly well determined, the engineer will be without much guidance either in carrying on intelligent development work, in estimating the tonnage contained in the ore-body or in prospecting intelligently for its extension.

This statement should not be construed as implying that a correct theory of origin is the *only* important factor in making developments, for that would be going to the other extreme. In any case the engineer will have available certain observations

and records—of natural outcrops, of borings and of test-pits, etc., and unless he has a fair idea of the origin and geological associations of the ore deposit, it will be impossible to interpret the observations and records properly. The two studies—of the facts of occurrence and of the probable mode of origin—should preferably be carried on simultaneously, in which case the conclusions reached can be checked as the studies progress.

On taking up the study of iron-ore deposition, it becomes apparent almost immediately that the investigation has certain great advantages as compared with the study of other ores; while on the other hand it presents a serious complexity. The advantages arise from the facts that most of our iron-ore deposits are of comparatively recent origin; that they have usually undergone little change since their formation; and that practically all of the processes involved in the formation of iron ores can be studied in action at the present day. As against these advantages is to be set the fact that in studying the iron ores we are dealing with common mineral forms of the commonest metal. The iron ores therefore present a greater variety of origin and occurrence than do most other ores.

It must be admitted, also, that in addition to the natural complexity and difficulties of the subject, added terrors are introduced by the literature which has grown up around it. These will be felt by anyone who attempts to acquaint himself with the status of existing knowledge in this line, and are due, not to the scantiness of existing literature but to its character. On inquiry the engineer will find that there are vast numbers of reports and papers dealing with the occurrence and origin of iron ores. But these papers differ remarkably in character and importance, and to one taking up the study of this mass of material without outside guidance the result would be confusion rather than enlightenment. Unfortunately the bulk of a paper, the form in which it appears, and even its readability give little aid in determining the probable soundness of the author's views.

In view of these conditions, it has seemed desirable in the present summary to re-state the facts and theories bearing on the subject in logical order, even though many of the facts of occurrence are well known to all engaged in iron mining. As for the theories of origin which are, or should be, based upon the facts, no attempt has been made to discuss or even name all that have

at various times been advanced. This is not a political discussion, and there is neither time nor space to permit indulgence in the pastime of calling some dead theory to life merely for the pleasure of killing it again.

The Principles of Classification.—Iron-ore deposits show so many variations in type that it would be difficult to discuss them intelligibly unless the discussion were preceded by some attempt at systematic grouping or classification. In preparing such a grouping it seems best to base it chiefly on the method of origin of the various deposits, for this basis is not only the most rational but the most generally serviceable in actual practice. The only danger is that it may be carried to such an extreme as to result in hairsplitting and useless distinctions, or that it will be based upon criteria which can not be definitely determined or applied in actual practice.

A logical classification should be sufficiently comprehensive that it will afford place for all known types of deposits; and its distinctions should be so clear and definite as not to permit or cause overlaps in the groups. If the classification is to represent anything more than a verbal exercise, the criteria employed in separating the groups must be based upon differences of real importance, and not upon merely trivial distinctions. If these three requirements are fulfilled, the classification resulting will be scientific as well as merely logical.

If we could stop at this point, the matter would not be so very difficult, but unfortunately it is also requisite that the classification should be capable of being put to some practical service. This requirement brings into view the real difficulty of the problem, and explains why we can not make use of some of the very obvious, clean-cut and scientific methods of grouping which have been proposed. If the criteria employed in subdividing the groups are of such a character that they can not be readily determined and applied in actual practice, the classification will be useless, no matter how interesting or suggestive it may otherwise be.

On reference to the table presented on page 9 it may be noted that iron is the third most abundant element among the constituents of the earth's crust, and that the two iron oxides together make up almost exactly 6 percent of the total. With such an abundant supply of iron, in various forms, distributed

widely throughout the different sedimentary and igneous rocks, and with the further knowledge that iron-ore deposits usually occur at or near the surface of the earth, in a zone freely traversed and acted upon by surface and sub-surface waters, it is obvious that the ultimate source of the iron necessary for the formation of any given ore deposit will usually be a matter of little interest or importance. It will in most cases be possible to prove that any one of half a dozen different rock formations, outcropping within a reasonable distance—vertically and horizontally—of the ore deposit, could readily have furnished all of the iron required. In a few cases, as when brown ores are the result of the alteration of nearby pyrite bodies, the ultimate source of the iron will be of serious interest. But in by far the majority of cases it can be disregarded as possessing neither scientific nor practical importance. The questions which do count, and which must be answered if we are to attempt any satisfactory grouping of iron ore deposits are two:

1. What was the general mode in which the deposits originated?
2. What were the factors which influenced the localization of the ores in their present geographic and geologic position?

The Major Groups.—As a starting-point we may assume that, since igneous rocks always contain notable percentages of iron in one form or another, there is a possibility that under favorable conditions such a concentration of iron might occur at some point in an igneous mass as to form a workable ore deposit. In this case we would have to deal with an original igneous deposit, contemporaneous with the cooling of the igneous rock itself. At least a few such deposits are known to exist, and consequently a place for deposits of this type must be made in any working classification.

In by far the majority of instances, however, the iron-ore deposit has a much less direct and more complicated history. Deposits of direct igneous origin make up certainly less that 5 percent—and possibly less than 1 percent—of the known workable iron-ore deposits of the world. The remaining 95 percent are deposits whose iron has been carried in by water, either surface or underground; or, in far rarer cases, by gases.

There is a great and fundamental division, in these water-formed and gas-formed ore deposits, beween those in which the iron was taken up by surface or sub-surface waters from ordinary

crustal rocks under ordinary temperature conditions, and those in which the iron was derived from heated igneous masses and was dissolved and possibly re-deposited under abnormal conditions as to temperature and pressure. It has been said that this division is fundamental in a genetic sense; but it must be added that it is unfortunately not available for use as a major division in a classification intended for actual use. For this reason the deposits thought to be due indirectly to the action of heated rock masses will in this volume be discussed merely as a subdivision (contact replacements) under the general class of replacement deposits.

After disposing in this fashion of the two classes of iron-ore deposits in which igneous action has any serious part—the original igneous deposits and the igneous contact replacements—we find that over nine-tenths of the ore deposits of the world, so far as total tonnage is concerned—are still to be reckoned with. All of these are formed by deposition from surface or underground waters; and in all cases the iron thus deposited was taken up from pre-existing rocks under ordinary temperature conditions. A brief summary of the processes involved will be of service as a guide in subdividing this enormous mass of deposits into groups of convenient size and reasonable uniformity.

The Removal of Iron from Crustal Rocks.—A relatively small amount of the iron minerals contained in rocks is freed physically, and carried off in suspension by running water. These suspended materials may come to be deposited later as iron sands. But by far the greater portion of the iron transported by water is carried in solution.

The iron contained in various forms in both igneous and sedimentary rocks is set free chiefly when these rocks suffer decay, though part of the iron may be leached out by percolating waters and removed while the rocks are still apparently fresh and unweathered. Most of the removal, however, is accomplished after the chemical and physical alteration of the rock has progressed to a stage where the originally firm mass has been weathered to a porous incoherent condition. It is then easily traversed by surface and sub-surface waters, and these can dissolve the iron and carry it off in solution.

When the rock contains its iron in the ferrous form, the process needs little explanation, for ferrous compounds are unstable and

soluble. When the iron was originally present as a ferric compound, however, which would be practically insoluble in pure waters, the process of removal is not quite so immediately obvious. In this case it is assumed that much of the solvent effect of the water is due to the fact that it carries organic acids, derived from its passage through decaying vegetable matter and soil.

The Transfer and Re-deposition of Iron.—When iron has once been taken into solution by flowing water, its final destination depends upon the course taken by the water. So long as the water does not suffer serious change in its velocity, its temperature or its chemical composition the iron salts will be carried along in solution, regardless of whether the water is flowing as a stream on the earth's surface, as a distinct flow through underground cavities or passages, or as a capillary flow through the rocks of the earth's crust. Under favorable circumstances the iron-charged water might reach the ocean without having any need or opportunity to deposit any portion of the iron which it carries. This is in fact the usual result, and the cases where ore deposition elsewhere *has* occurred, are less common. Since we are interested particularly in this last class of results, however, it will be well to study their history in more detail.

Water carrying iron in solution may be forced to deposit part or all of this iron, and this deposition may be caused by physical, chemical or organic agencies. It would be idle to attempt to catalogue all the possible causes of such deposition; but those of the greatest importance are as follows:

1. Iron-charged waters traversing limestone beds are apt to deposit iron carbonate and to dissolve lime carbonate, this transfer being due to the relative solubilities of the two carbonates.

2. Iron-charged waters which for any reason experience a decrease in temperature, pressure or percentage of dissolved carbon dioxide will deposit iron compounds as a consequence.

3. Iron-charged waters coming to rest in an enclosed or partly enclosed basin will, as evaporation and chemical reactions affect them, deposit iron compounds.

4. Iron-charged waters may also deposit iron compounds as the result, either direct or indirect, of organic agencies.

All of these principal causes of iron deposition will be discussed in more detail in the following chapters.

The Alteration of Existing Deposits.—The water-formed deposits so far considered result in the formation of a new ore deposit in a new place. But there are several types of iron-ore deposits which owe their present location or form or character to the fact that a pre-existing deposit of iron mineral has been more or less altered or re-made. The chief factor in the alteration is commonly, as in the other groups, surface or sub-surface water; but the element of transport by water is either not present at all, or it enters in only a minor degree. These deposits are conveniently called Alteration Deposits.

The alteration deposits include two important and well-known types, and a third of less importance except locally. The two important groups are the Residual ores and the Gossan ores. In the first class an iron-bearing rock has been leached of its non-ferrous constituents, so as to leave behind a relatively enriched mass of iron ore. In the second, a pyrite body has been altered, in part at least, to iron oxide. In the third and least important class, which can be best treated as a merely local phenomenon, a pre-existing, iron ore deposit has been changed in mineral character by metamorphism or local igneous action.

Summary of Working Classification.—By making use of the data presented on the pages immediately preceding, it is possible to develop a working classification of iron-ore deposits which will be fairly satisfactory, both as regards logical completeness and practical utility. The grouping suggested in the following table has been adopted for use in this volume.

SUMMARY OF CLASSIFICATION OF IRON-ORE DEPOSITS

A. Sedimentary or bedded deposits.
- A. 1. Transported concentrates.
- A. 2. Spring deposits.
- A. 3. Bog and lake ores.
- A. 4. Marine basin deposits.
  - I. Carbonate deposits.
  - II. Silicate deposits.
  - III. Oxide deposits.

B. Replacements and fillings.
- B. 1. Cavity and pore fillings.
- B. 2. Normal replacements.
- B. 3. Secondary concentrations.
- B. 4. Contact replacements.

C. Alteration deposits.
- C. 1. Laterite deposits.
- C. 2. Solution residuals.
- C. 3. Gossan deposits.

D. Igneous deposits.
- D. 1. Magmatic segregations.

Relative Importance of the Groups.—In any general discussion of the origin of iron-ore deposits, it is necessary to consider many possible types of origin, as has been done in the grouping presented above, and as will be done in more detail in later chapters.

Though this method of treatment adds to the thoroughness and completeness of the discussion, and though it appears to be logically a necessity, it has the very unfortunate defect of causing the reader to lose sight of the real relative importance of the various types or classes discussed. For that reason it seems desirable to emphasize here one very important fact regarding our workable supplies of iron ore:

There are many ways in which iron ore deposits can originate, but only a few of these possible modes of origin have given rise to deposits of serious commercial importance. Practically all the known iron-ore supply of the world is, and will be, derived from (a) *sedimentary basin deposits, from* (b) *replacement deposits, or* (c) *residual deposits. Of these, the sedimentary ores are of by far the greatest importance.*

The correctness of this statement of the case will be seen when the facts are examined, for it is now fortunately possible to place the matter on a quantitative basis.

For comparison with the theoretical or textbook importance of the various types of iron-ore deposits, we have available estimates of reserve tonnage on three of the continents—North and South America, and Europe. The scattered data available for the three remaining continents are of little service for any purpose.

As a basis for our subdivision by types, the following estimates may be tentatively accepted as being close enough for our purposes. The figures for Europe are taken unchanged from the International Geologic Congress report on the iron ores of the world; those for North and South America are as given in Chapter XXIX of the present volume.

Area	Reserve tonnage
Newfoundland and Canada	4,150 million tons
Lake Superior district	2,500
Southern United States	3,750
Eastern and western U. S.	1,300
Cuba, Mexico, etc.	3,060
Total North America	14,760 million tons
South America	8,000
Europe	12,032
Total, three known continents	34,792 million tons

As soon as we attempt to divide these totals among the classes of ore deposits described in current literature, several facts become obvious. First, the total tonnage of bog ores and beach sands known to exist anywhere in usable condition is so small that no space need be reserved for either class in our new grouping. Second, since the titaniferous ores are omitted, the class of magmatic segregations has no very certain representative left. Under these circumstances, it seems best to throw all the doubtful magnetites into the same group.

Tabulated in the same order as in the preceding table, we get results as follows; the quantities being given in millions of tons.

	North America	South American	Europe	Total	Percent
Bog ores and beach sands......	0	0	0	0	0.0
Sedimentary basin deposits.....	6,030	7,500	8,407	21,937	63.1
Normal replacements..........	310	0	1,441	1,751	5.0
Secondary concentrations......	2,750	0	0	2,750	7.9
Contact deposits..............	680	350	507	1,537	4.4
Residual deposits.............	4,350	0	272	4,622	13.3
Magmatic segregations........	0	0	0	0	0.0
Doubtful magnetites..........	640	150	1 405	2,195	6.3
Totals, millions of tons......	14,760	8,000	12,032	34,792	100.09

On studying these comparative tables, it would seem that the real importance of the sedimentary ores has been heavily underrated even by the best authorities. The fact that, of the world's five great competitive steel centers, four depend largely or entirely upon ore of this type does not appear to have been noted. It might be added that the above estimates are based upon ore of current commercial grade; if we assumed that lower grade ores would in time be used, the percentage of the sedimentary reserves would be still further increased. For current estimates, however, we may assume that the sedimentary ore reserves contain about two-thirds of the world's iron supply; and that all of the igneous and doubtful ores together make up about one-sixteenth of the world's reserve.

The comparison may, indeed, be carried further with even more striking results. If we add together all the ores which *anyone* considers to have originated by magmatic segregation, all the ores which are due to contact action, and all of the magnetites whose origin is in doubt, we find that the total amounts to less than 11 percent of the known ore reserves of the world. We

may fairly say, therefore, that stretching the theory of igneous action to its greatest possible extent, and including all ores which anyone considers may be due to it, directly or indirectly, we get results which compare as follows:

Direct sedimentary deposition..........	63.1 percent
Surficial weathering and chemical action.	26.2
Igneous action, direct and indirect......	10.7
	100.0 percent

The Ratio of Geologic Concentration.—Some of our known iron-ore deposits are so impressive as to size that it is difficult to remember that they bear an almost infinitely small relation to the amount of iron not concentrated into ores, but disseminated throughout the rocks which form the crust of the earth. All of our known ore deposits must have originally been derived, by a series of changes and concentrations, from such disseminated iron. The extent to which this concentration has been carried is a matter of serious geologic importance; and since it is possible to determine it with all the precision which the problem warrants, the following calculations have been prepared.

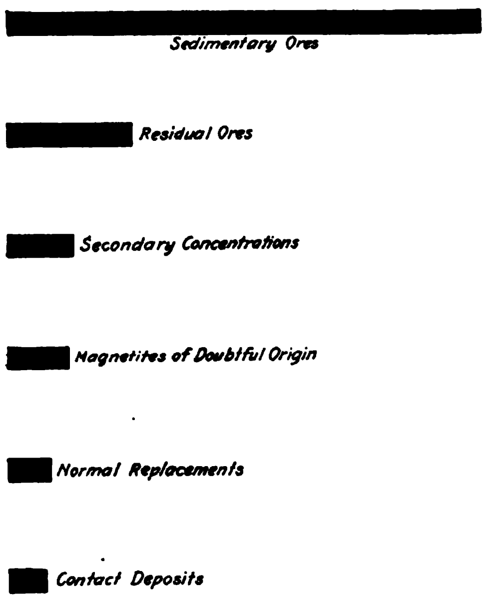


Fig. 3.—Relative importance of various types of iron-ore deposits.

According to Clarke's latest estimates, the crust of the earth averages 4.44 percent metallic iron. On this basis, that portion of the crust which underlies the United States, to a depth of 1000 feet, should contain a little over 275 millions of millions of tons of disseminated iron.

To compare with this enormous total, we can not estimate the present known ore deposits of the United States, of current commercial grade, at much over 7500 million tons, containing possibly 3300 million tons of metallic iron, as is shown in a later chapter of this volume. The ratio between total disseminated iron and total commercial ore is therefore over 80,000 : 1. Even if we lower our ideas of grade so as to include 35 percent ores in the Lake region and 25 percent limey ores in the South, the ratio would still be over 8000 : 1. At the most, therefore, only about one-hundredth of 1 percent of the theoretically available iron in that portion of the earth's crust has been placed in commercially available form by geologic agencies.

The Geologic Age of Iron Deposits.—Iron-ore deposits, as now found, are associated with rocks of different geologic age. In some cases, as in the basin deposits described in Ch. V, the ore deposits were formed at the same time as the rocks which now enclose them, and are therefore of the same geologic age as those rocks. In other cases, however, as in the replacement deposits (Ch. VI), the ore was deposited long after the rocks were formed, and in these cases the ore deposit is geologically of a different age from its associated rocks.

The matter in which we are chiefly interested is not the age of the enclosing rocks, for that is often purely incidental, but the age of the ore deposits themselves. When this matter is taken up on a sufficiently broad basis, with an adequate supply of data on which to base conclusions, we find that the iron ore deposits of the world are not, so far as geologic age is concerned, purely as a matter of accident. There appear to have been certain periods in which no iron deposits of serious importance were formed anywhere; while at certain other periods the conditions favoring iron deposition appear to have been generally favorable. Five such important periods of iron deposition can be made out with some certainty, and are worthy of brief attention:

1. In the earliest geologic age—the pre-Cambrian or Archæan—the conditions favored iron deposition more generally than in any subsequent period. The rocks then exposed at the surface carried notably higher percentages of iron than the average would now show; and it is possible that during some portions of this period chemical activities were greater than in later ages. Whatever the reason, the pre-Cambrian rocks all over the world carry

important iron-ore deposits. During this period, for example, the original lean ores were laid down in the Lake Superior basin, which since their original deposition have been so concentrated as to yield our present ore deposits. Elsewhere hematite and magnetite deposits of this age are relatively common.

2. The next important period of iron deposition covers the upper Cambrian and lower Silurian periods, whose rocks contain the well-known bedded red hematites of Newfoundland, of eastern Canada and of the eastern and southern United States.

3. During the Carboniferous period, in Europe and the eastern and central United States at least, iron deposition became active again, owing probably less to any great amount of free iron available than to the excessive amount of reducing agencies available. The result is that, associated with the coal series, we have relatively thin and low grade, but very extensive, deposits of iron carbonate. Owing to their close association with coal, these carbonate deposits have an industrial importance which would not be otherwise warranted by their thickness or grade.

4. In the Jurassic formations of western Europe a series of bedded ores appear, closely similar to our own Clinton hematites in character and origin. These ores, particularly in the Luxembourg-Lorraine basin, are present in heavy tonnages, and are particularly important factors in the world's iron and steel trade.

5. During the Tertiary age conditions favored deposition of brown ores in many portions of the world. The brown ores of Cuba, India and the southern and eastern United States were, in practically all determinable cases, deposited during the Tertiary. These brown-ore deposits are, of course, associated with rocks of varying geologic age, but the ore deposits themselves are very uniform in time of origin.

CHAPTER V

SEDIMENTARY OR BEDDED DEPOSITS

This group of iron-ore deposits includes such as occur in true beds or strata, the iron having been originally transported in suspension or solution by running water, and having been deposited from such suspension or solution by purely mechanical action, by evaporation, by chemical reactions or by organic agencies. Such deposition takes place at the earth's surface, and the deposits are usually made in bodies of water. The ore deposit so formed may later be covered by a bed of some other rock, in which case the ore deposit will necessarily be younger than the rocks which underlie it and older that those which overlie it. In all of its essential features a sedimentary ore deposit, as worked to-day, is in just the same condition as when its deposition was just completed, though subsequent metamorphism or other action may have changed it in some less important regards.

The deposition of iron ores by purely sedimentary processes has gone on during all of the known geologic periods, and the important deposits of this type range in age from pre-Cambrian to Cretaceous. They are remarkable among ore deposits, not only for the enormous tonnages concerned and the areas covered by groups of deposits, but for the size and continuity of individual deposits or beds. Instances of these will be given later.

Iron ores of purely sedimentary origin make up a far more important class than might be suspected by reference to current literature on ore deposits. Of the total known commercial iron-ore reserves of the world, the sedimentary ores make up about two-thirds in tonnage; and of the lower-grade ores which may perhaps be used in future, they constitute an even larger fraction. The iron and steel industries of the Rhine, of Middlesboro, of Belgium, of France, of Alabama and of Nova Scotia are based, largely or entirely, upon ores of sedimentary character. The only really important deposits which are not of purely sedimentary origin are those of the Lake Superior district, and even these are modified and enriched sediments.

These facts are ample justification for devoting to sedimentary ores far more space, in the present volume, than is commonly assigned to them. We are dealing with a class of ores upon which most of the world's present mining and metallurgical practice is based, and on which we may depend still more heavily in future. The facts relative to their characters and occurrence, and the theories as to their origin, must therefore possess an importance which could hardly be overrated.

The sedimentary ores agree in that they were all transported, in solution or suspension, by surface waters to their place of deposition; that they were deposited in substantially the same form in which they are now found; and that they form sedimentary beds, associated and interstratified with other sedimentary rocks. Beyond this, however, there were wide differences as to the details of the mode of deposition, and the ores themselves differ greatly as regards mineral character, grade, etc. Some of these points of agreement and difference may be profitably touched upon in the present place, before going on to a discussion of the separate types or classes.

It has been noted that the sedimentary ores differ widely in mineral character. As a matter of fact, they include all the normal iron minerals, for we find that different sedimentary deposits may consist predominantly of magnetite, of hematite, of a brown ore, of carbonate, or of one of several iron silicates. Of the better-known deposits, those of Newfoundland, Brazil, and Alabama are hematites; those of Lorraine are brown ores; while the Middlesboro ores are carbonates.

Further, the difference in grade of ore is equally marked, ranging from 25 to 30 percent metallic iron for the English carbonates and the poorer Lorraine ores, through 33 to 37 percent for the southern Clinton ores and the better ores of French Lorraine, up to 52 percent and over for the Newfoundland ores and well above 60 percent for the Brazilian hematites. Along with this range in iron content is a wide range in sulphur and phosphorus; though if the Brazilian and beach sand ores be excepted there would be more uniformity in these regards. Excluding these two exceptional types, we might fairly say that the sedimentary ores are normally high in phosphorus and often rather high in sulphur. More detailed data on these points will be presented later.

As to mode of origin, there are two widely contrasted types of sedimentary iron ores. The first, which is of little commercial importance, includes the deposits of purely mechanical origin, in which the ores were carried in suspension as particles of iron mineral, and finally deposited along beaches or elsewhere in a water basin. The second class includes the highly important cases in which the iron now included in the ores was transported by surface waters in solution, and was finally deposited through chemical or organic agencies.

In our further discussion of the sedimentary ores it will be convenient to make use of some of these differences in method of origin and types of deposit in order to subdivide this large class of ore deposits into units of workable size. In doing this, the mechanically formed sediments will of course make up one separate class, as distinguished from those formed by deposit from solution. It would be pleasant if we could go further, and subdivide this second sub-class according to the exact mode in which its ores were deposited. But in the light of our present knowledge such a purely genetic classification would not give results that could be applied in actual practice, so that some compromise must be arrived at between theoretical accuracy and practicability. The grouping which has been adopted for the present work is as follows:

Sedimentary Iron Ores.—A. Deposits of mechanical origin, in which an iron mineral, derived from the decay of a pre-existing rock, is carried in suspension by surface water and finally deposited by purely mechanical agencies.

1. *Transported concentrates;* deposits of an iron mineral (usually magnetite) along stream beds, sea beaches, etc.

B. Deposits of chemical origin, in which iron, carried largely or entirely in solution by surface waters, is deposited as a chemical precipitate, with or without the aid of organic action.

2. *Spring deposits;* iron deposits made by springs at their point of issue. Unimportant commercially, but mentioned as affording an interesting link with another type of deposit.

3. *Bog deposits;* in which iron minerals (brown ores, pyrite or carbonate) are deposited in swamps or lakes chiefly as the result of organic action.

4. *Marine basin deposits;* in which iron ores are deposited in a completely or partly enclosed sea-basin, as the result of evapora-

tion, chemical reactions, or organic agencies. This group includes three fairly distinct sub-types, differing not only in the common iron mineral occurring, but also in their structural and genetic relations.

4*a*. *Marine carbonate deposits.*
4*b*. *Marine silicate deposits.*
4*c*. *Marine oxide deposits.*

The order in which the preceding classes have been arranged is that of our knowledge concerning their exact mode of origin. It happens, it may be interesting to note, that this is almost the exact reverse of the order of their commercial importance.

A. 1. TRANSPORTED CONCENTRATES

This term will be here applied as a convenient general name for the deposits, of mechanical origin, which are formed when iron minerals which have been carried in suspension by running water are finally deposited. It will therefore include deposits of the stream placer type, as well as the beds of beach sand, river sand, etc., which occasionally attract attention as possible sources of iron. Except for the use of the Japanese sands and the recurrent interest in the St. Lawrence deposits, this group could be dismissed with little notice. In practically all cases the iron mineral in these deposits is magnetite.

The deposits are formed when a stream or ocean current is supplied with fine grains of magnetite or hematite, generally derived from the decay of igneous or metamorphic rocks. If the supply be large and steady enough, the iron mineral may be carried along until the velocity of the current is checked at some point, and there a deposit of iron sand may form.

It is obvious that such deposits of iron sands as may be formed along small streams, or along the upper courses of rivers, are unlikely to be of sufficient size to be of even local use as sources of iron. On the other hand, at favorable positions along the sea-coast, or on the lower tidal reaches of large rivers, we do find iron-sand deposits which are of size sufficient to justify attention. The two difficulties which generally intervene to prevent any serious commercial use are (1) that many of the deposits carry undesirable and difficultly separable minerals a long with the magnetite, and (2) that storms cause so much shifting in the sands as to prevent economic working.

B. 2. SPRING DEPOSITS

Underground waters carrying iron in solution are apt to deposit a portion at least of this iron at points where they reach the surface as springs. These spring deposits are occasionally of considerable size, but their principal interest arises from the fact that they form a connecting link between the surface or sedimentary deposits described in the present section, and the underground cave fillings later described.

The deposition is usually due to loss of carbon dioxide, and consequent precipitation of part of the iron which the water has been carrying. The ore as deposited is commonly a loose, porous mass of brown ore; but occasionally the concurrent deposition of lime carbonate results in the formation of a more solid deposit of mixed iron oxide and lime carbonate.

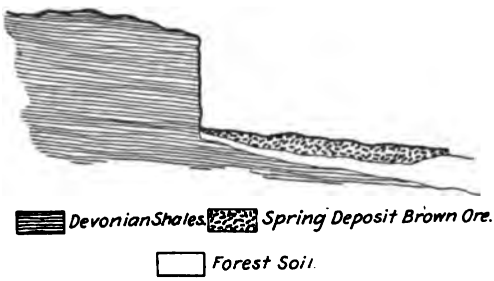


FIG. 4.—Spring deposit of brown ore, West Virginia.

When free from lime carbonate, the porous brown ores deposited by springs are normally high in iron and combined water, and low in phosphorus. They may be either very high or very low in sulphur, according to the source from which the spring water derived its iron.

As previously noted, the chief reason for the discussion of spring deposits is that they are related both to the bog ores next to be described, and to the cave deposits discussed in Chapter VI.

B. 3. BOG DEPOSITS

When surface waters carrying iron in solution enter a pond or bog charged with decaying vegetable matter, reactions take place which usually result in the precipitation of a bed of spongy brown ore. These bog ores are of no particular importance at the present day, and do not deserve the space which is commonly accorded them in the literature of the subject. It was at one

time believed that many of our commercial brown-ore deposits originated in this way, but later investigations have showed that most workable brown ores are formed in far different fashion than the bog ores.

Surface waters, carrying iron in solution in the form of carbonate, sulphate or as an organic compound, tend to deposit their iron in bogs, swamps or lakes. The deposition is in part due to simple loss of carbon dioxide by exposure to the air, and in part to more complex reactions dependent upon the presence in the water-basin of abundant animal or vegetable matter. The ore may be deposited as brown ore, as carbonate or as sulphide; but normally whatever its immediate form of deposition it will ultimately revert to the stable hydrated oxide—brown ore.

Bog ores have been worked steadily, to a small extent annually, in Quebec and in Sweden; while in England and the United States small tonnages have been mined in times past. They are normally high in phosphorus; and vary greatly in sulphur content.

ANALYSES OF BOG AND LAKE ORES

	1	2	3	4
Ferric oxide	60.74	70.04	69.64	67.50
Ferrous oxide	.....	......	0.72	....
Manganese oxide	1.18	1.78	2.99	1.45
S lica	13.94	7.84	8.17	7.81
Alumina	2.59	2.20	2.43	4.18
Lime	3.47	0.32	......	0.47
Magnesia	0.93	0.27	0.60	0.23
Sulphur	0.078	0.093	0.036	......
Phosphorus	0.302	0.331	0.205	0.081
Loss on ignition	16.49	16.84	15.00	17.81
Metallic iron	42.52	49.03	49.31	47.22

1, 2, 3. Bog ores from Three Rivers district, Quebec. Griffin.
4. Swedish lake ore. Phillips.

B. 4. BASIN DEPOSITS

The class now to be discussed includes some of the most important iron-ore deposits of the world, from an industrial point of view.

Iron ores of this type form extensive deposits, interbedded with shales, limestones and other shallow water marine formations. The ores themselves appear to have originated chiefly by deposition from solution, the deposition commonly taking place in

shallow marine basins, which were at times partly or entirely cut off from the sea. Two of the three sub-classes to be considered are of purely marine origin; but the third—the iron carbonates—includes beds deposited under brackish water conditions as well as marine beds.

All of the deposits included under the general class of Basin Deposits agree in their broad mode of origin; but the class contains a very large number of deposits of great tonnage and industrial importance, and differing among themselves not only as to the details of their origin but still more widely in the character and associations of their ores. It will be convenient, therefore, to make some subdivision of the general group. If the details of the origin of all of the deposits were definitely known, it would be possible and perhaps advisable to make this subdivision along purely genetic lines, but at present this can not be done satisfactorily. The grouping adopted for the present volume is based rather upon the character and usual associations of the ores than upon other grounds, although as will be seen there are accompanying differences in mode of origin. The three sub-classes accepted will include respectively (1) the sedimentary iron carbonate ores; (2) the iron silicate ores, and (3) the iron oxide ores occurring as marine sediments. The order in which these three types are named is not that of their industrial importance, but rather that in which their relative modes of origin can be best taken up.

4a. BASIN DEPOSITS—IRON CARBONATES

Associated with marine sedimentary beds of various ages bedded deposits of more or less pure iron carbonate are found. The ores may vary greatly in their grade, in their age and associations, and to some extent in the details of their origin. But on the other hand, there are certain broad points of resemblance which make it advisable to group together all of the sedimentary carbonates. The points, both of general resemblance and of individual difference, can be best understood and balanced if the different features of the deposits are taken up separately.

Extent of the Deposits.—In the extent, both of the individual deposits and of the general areas of ore deposition, the carbonate ores are remarkable. In the first regard—the size of the larger

individual ore beds—they are surpassed only by some of the marine oxide deposits later discussed. In the second regard—the areas over which ore deposition was in progress at a given time—the carbonate ores of some series will probably surpass even the Clinton ore beds.

Age and Associated Rocks.—Since conditions favoring the deposition of bedded iron carbonates have occurred frequently during all periods of geologic history, we find that the industrially important deposits have a very wide range in geologic age. In different countries carbonates are worked from beds varying from the Devonian or earlier to the Cretaceous. In some cases the older carbonate ores have been altered, through the general metamorphism of the region in which they occur, and now appear in forms somewhat different from those in which they were originally laid down. In general, however, the commercial ores are of quite simple type and relations.

The rocks most commonly and intimately associated with beds of iron carbonate are beds or layers of clay and shale. These are frequently high in organic matter; and at times the carbonate ores are found in close association with coal beds.

On a later page, in discussing the English ores, sections are given of the ore beds in the Middlesboro district. At present a section of the strata involved in one of the many carbonate beds of South Wales, quoted from Kendall, will be of more service.

	Feet	Inches		Feet	Inches
Ironstone (carbonate)	0	3	Shale	3	10
Shale	0	11	Ironstone	0	5
Ironstone	0	1	Shale	3	3
Shale	2	4	Ironstone	0	1
Ironstone	0	1	Shale	0	9

The 12 feet of the section contain, it will be noted, five layers of iron carbonate and five beds of shale; and the aggregate thickness of iron carbonate is only 1 foot. Of course there are richer sections than this in the Dowlais district, but this will do to exemplify the alternations in the series.

Structure of the Ores.—There are two general types of structure which are common among iron carbonate ores. First, and by far more frequently, the ores are found in nodular or concretionary forms, in beds of clay or shale. Second, the ore is occasionally found as a massive structureless layer or bed.

Whether occurring as concretion or as separate bed, the carbonate ores rarely show any trace of internal structure except the concentric layering due to concretionary origin. Occasionally, however, carbonate ores are found which under the microscope show a more or less definite oolitic structure. But they rarely if ever show such oolitic structure with the perfection or the frequency with which it occurs in the sedimentary oxide ores.

Composition of the Ores.—The iron carbonate ores are all usually of low grade, as compared with the average magnetite, hematite or brown ore. This is due partly to the fact that even a theoretically pure iron carbonate is not a particularly rich source of iron—for pure siderite carries only 48.2 percent metallic iron, as compared with the 70 percent carried by pure hematite. A partly counter-balancing advantage, of course, is that the carbon dioxide which makes up the remainder of the siderite can be driven off readily by heat, thereby materially improving the grade of the ore at relatively little expense.

Aside from this natural and necessary lowness in iron, the carbonate ores usually carry considerable foreign matter. I some cases part of the impurity is lime carbonate; in others it is clayey matter (silica and alumina); in still others it is carbonaceous material.

The following analyses will serve to give some idea of the composition of carbonate ores from various widely scattered British localities.

ANALYSES OF IRON CARBONATE ORES

	1	2	3	4	5
Ferrous oxide	35.37	36.14	41.03	46.53	41.65
Ferric oxide	1.93	1.45	0.41	0.05	.....
Manganese oxide	1.00	1.38	0.55	2.54	.....
Silica	10.22	17.37	13.35	1.93	0.52
Alumina	6.95	6.74	5.79	1.22	0.96
Lime	6.63	2.70	3.00	2.44	5.76
Magnesia	3.73	2.17	3.36	1.39	3.52
Sulphur	0.10	0.05	.....	0.19	0.25
Phosphoric acid	1.15	0.34	0.70	0.69	0.84
Carbon dioxide	22.02	26.57	28.49	30.77	33.08
Organic matter	1.20	2.40	0.07	10.47	11.16
Moisture	9.80	1.77	1.93	1.47	2.04

1. Bedded carbonate, Jurassic age, Middlesboro, England. Kirchhoff.
2. Bedded carbonate, Lowmoor, Yorkshire. Kendall.
3. Bedded carbonate, Dowlais, Wales. Kendall.
4. Blackband ore, North Staffordshire. Kendall.
5. Blackband ore, Clyde basin, Scotland. Kendall.

Allowance must be made, in looking over these results, for the fact that the Middlesboro ore as mined is partly hydrated. Setting this aside, the other obvious difference is between the clayey carbonates and the carbonaceous or blackband ores. Reference to the analyses will show that the blackband ores are normally far lower in silica and alumina than are the ordinary or clayey carbonate ores.

Origin of Marine Carbonates.—It has been noted that the iron carbonate beds differ little in origin from bog-ore deposits. In reality, the chief reasons for discussing them separately are the somewhat different geologic associations of the carbonate beds, and their far greater industrial importance.

One general process by which sedimentary iron carbonates can be formed is well understood, and as its acceptance does not involve postulating any unusual conditions or agencies it is commonly accepted as applying to most carbonate beds. It is assumed that surface or underground waters, charged with carbon dioxide, pass over or through rocks from which the waters extract iron. This iron, carried in solution as ferrous bicarbonate, finally reaches the neighborhood of the sea. Here, in brackish water swamps or lagoons, and in the presence of abundant vegetable matter, part of the carbon dioxide is abstracted from the water. The deposition of ferrous carbonate follows.

When the iron carbonate is deposited in a swamp, it is apt to be precipitated as a separate bed, mixed with more or less organic matter; and thus gives rise to such deposits as the blackband ores. On the other hand, when deposition takes place in a less stagnant basin, clayey matter is apt to be precipitated along with the iron carbonate. In this case the carbonate may be originally laid down as particles diffused through the mass of clay, and the later segregation of these particles would yield the concretionary and nodular clayey carbonates.

4b. BASIN DEPOSITS—IRON SILICATES

Iron silicates are used as ores at only a few points in central Europe, and from a purely industrial viewpoint would not require serious attention. But their mode of deposition is a matter of high importance, since many of the sedimentary oxide deposits, next to be considered, have been ascribed to the same general method of origin. Some discussion of the occurrence and relations of the marine silicates will therefore serve as an introduction to the more important and complicated oxide deposits.

The Glauconites of the Ocean Bottom.—The discovery that glauconite deposits are now forming over extensive areas of the present ocean bottom was one of the results of the *Challenger* explorations, and the publication of these results may be regarded as the starting-point for all modern discussion of the origin of sedimentary iron silicates. The facts which were observed in the course of the *Challenger's* work, and the explanation of these facts given by Murray and Renard, have profoundly influenced later thought on subjects to which neither facts nor theory were particularly applicable. Geologists have used them in explaining the origin of the oolitic oxides, apparently without noticing that this was simply introducing an unnecessary and very complex element into an already difficult problem.

The glauconite found on the present ocean bottom fills microscopic shells and occurs fringing the shore lines, at a distance beyond the immediate sphere of coarse mechanical deposition and at depths of 100 to 200 fathoms usually. Murray and Renard held that the process of glauconite formation involved the filling of the small shells with fine silt or mud, containing of course some iron compounds as do all muds. The organic matter of the dead animal, and the sulphates contained in sea-water, furnish the chemical agents necessary for the subsequent changes. The iron compounds of the mud are altered first to sulphides, and later oxidized to ferric hydroxide. Simultaneously the alumina of the mud is dissociated from the silica, and the latter reacts upon the iron oxide, finally combining with potash compounds to form the ultimate potash-iron silicate glauconite.

This explanation is technically sound, and fits all the requirements of the deposits which Murray and Renard had under particular observation. It also furnishes a satisfactory explanation of the occurrence of glauconite grains in shales, a feature fairly common in Cambrian and later rocks. How it applies, or fails to apply, to other greensand deposits will best be understood if we describe briefly some of the conditions which have to be met.

The Cretaceous Greensands of New Jersey.—The glauconite deposits occurring in the Cretaceous rocks of New Jersey have been selected as a basis for discussion, because very definite data are available with regard to their stratigraphic and chemical characteristics.

In the Cretaceous series of New Jersey, whose total thickness may be 700 feet or thereabout, there are three very definite and thick beds of greensand and several beds of clayey or sandy greensands. The purer greensand beds range, individually, from 10 to 50 feet in thickness; the three beds together give an average total thickness of perhaps 90 feet. If we include the greensand contained in the less pure beds, it might be within limits to say that during Cretaceous time over 125 feet of pure greensand was deposited all over the New Jersey Cretaceous area.

So far as can be determined by drilling, the greensand formations extend seaward at least to the present coast-line and probably beyond. Taking into account only the present extent, therefore, we have to deal with an area some 120 miles in length and 40 miles in width. The thickest of the three greensand beds, deposited over this area, required approximately 75 thousand million tons of iron oxide to account for the greensand which it contains. The total greensand in the Cretaceous series, on the same basis, may have required some 250 thousand million tons of ferric oxide. When these facts are once brought into view, it becomes obvious that the problem of greensand deposition in quantities of such magnitude involves somewhat different factors from those which might account for the formation of isolated glauconite grains in a bed of mud.

One point in regard to the real composition of these iron silicates may be worthy of consideration. It is generally assumed that the small dark-colored granules are homogeneous, and the current analyses of glauconite and other silicates are based on this supposition. My own experimental work on glauconite, which has been rather extensive, tends toward another conclusion. Apparently, whenever a greensand granule is dissociated carefully, it will yield a thin shell of silica, enclosing or enclosed by the green iron silicate. If this turns out to be the normal condition, we must evidently make allowance for the enclosed silica in all analyses. It might easily be true that of the 50 percent or so of silica which is supposed to be a component of glauconite, less than 35 percent is really part of the glauconite mineral, the remainder being merely an associated material. In that case the iron silicate as precipitated would really be richer in iron than has been usually considered.

Aside from the greensand deposits, the other Cretaceous rocks of this area are mostly clays and sands. Limey beds are rare; and with one local exception no distinct and separate bed of limestone exists. On the other hand, all the Cretaceous rocks include large quantities of shell matter. The greensand beds themselves are made up largely of glauconite granules, with considerable quartz sand, some fine clay, and some shell matter.

So far as the land conditions which accompanied these Cretaceous deposits are known, it may be said that low-lying shores, with a deeply weathered land surface, faced the Cretaceous sea. No trace of contemporaneous volcanic or other igneous activity exists.

Reverting to the quantitative data which have been supplied in preceding paragraphs, it can be seen that an immense tonnage of iron oxide reached the sea-bottom in one form or another. If this were in the form of iron disseminated through mud, then something over three million million tons of such mud were absolutely leached of their iron to provide sufficient to form these Cretaceous green-sands. As a matter of fact, there is not the slightest reason to believe that this amount of mud was deposited in the space now occupied by the greensand; and the clays which overlie the greensands have *not* been leached at all, but contain normal iron contents.

In order to adequately explain the relations, we must assume that the original deposit was not a clay containing disseminated iron, but a relatively pure, fine-grained iron sediment, carrying down with it a smaller proportion of clayey matter. A deposit of this type, reacting with organic matter, could furnish greensand deposits of the size and character which are now found.

As to the cause of this exceptionally rich iron deposition, there are available two possibilities, which may be either alternative or supplementary. The waters of the basin may have been, temporarily, exceptionally high in iron content; or an exceptionally powerful precipitating agent may have been at work. Drainage from the Triassic areas of sandstone and trap might have supplied iron-rich waters; climatic conditions may have favored precipitation by evaporation; or changes in the character of the waters entering the basin may have brought about deposition through chemical reactions. The matter may be dropped at this point, though it will be necessary to recur to it when the marine oxide ores are under discussion.

Silicate Ores of Europe.—The silicate ores of central Europe do not offer any difficulties beyond those encountered in discussing the greensands of the New Jersey Cretaceous. In fact they are less difficult in one way, for the beds are far thinner and less extensive areally. Further than that, they are associated with beds of oölitic oxide ores, so that the proof as to direct iron deposition is strengthened.

These European silicate deposits include thin beds of the minerals thuringite and chamosite, whose composition has been discerned in Chapter II.

4c. BASIN DEPOSITS—IRON OXIDES.

The ore deposits included under this particular sub-class comprise the most extensive ore reserves now known; for they include the Clinton ores of the southern and eastern United States and eastern Canada; the Wabana ores of Newfoundland; the minette ores of Lorraine and Luxemburg; and the Minas Geraes ores of Brazil; together with numerous less important deposits. In tonnage they make up over half the known iron ores of the world. So far as the question of origin is concerned, the Lake Superior ores might also be included here, for most of the questions which arise concerning the origin of the minette and Clinton ores would also come to the front if we went back far enough in the history of the Lake ores. Because of their later alteration and re-concentration, however, the origin of the Lake Superior ores will be discussed elsewhere.

Ores of the type here considered are so important and so widely distributed that little attention has been paid to their origin and general geologic relations. Much attention is paid to the subject of igneous ores, which may or may not really exist; and extensive discussion is based on the phenomena of contact deposits, which were apparently formed to be the bane of both engineer and furnaceman. Such literature as does exist relative to these vast basin deposits of hematite and brown ore shows certain limitations; it is based largely upon work with the microscope, which gives delicate but limited results, and it is contributed very largely by paleontologists, who tend to regard iron-ore beds chiefly as burial grounds for interesting fossils. Under these circumstances little apology need be offered if, in the present volume, the bal-

ance swings over-low on the other side, and perhaps too much attention is paid to a discussion of structure and general geologic relations.

On certain points there is substantial agreement among all the ores included in this sub-class; on others there is more or less wide variation. All of the deposits are in true sedimentary beds, associated with various other sedimentary rocks. The beds vary in thickness and number; and the ores vary in grade. In mineral character they are mostly hematites, though the minette ores of Lorraine and Luxemburg are hydrated or brown ores.

In discussing the associations and general relations of the oxide or "oölitic" ores, the bulk of the illustrative material is naturally drawn from the Clinton ores of the United States and Canada, and the earlier Ordovician ores of Newfoundland. With the Clinton ores I am personally familiar throughout most of their range, and I have spent some time on a study of the Newfoundland deposits. For local details there are also available the very careful measurements by Burchard of various southern Clinton ore beds, and the excellent data secured by the Nova Scotia Steel engineers at Wabana. For the Luxemburg–Lorraine deposits there is, of course, a large mass of published information. With regard to the ores of the Minas Geraes district of Brazil, which, according to several eminent geologists, fall in this class, less can be said. The reports available on this district deal rather with the ores themselves than with the details of their stratigraphy and associations.

Extent of the Deposits.—Perhaps the most satisfactory starting-point for a discussion of the general relations and origin of these ores will be to attempt to secure some definite idea as to the extent of the individual ore beds, and of the general areas of ore deposition. Whenever we have sufficient data, as is the case regarding the Clinton ores, we find that these are two very different matters.

Taking up first the extent of individual ore beds, it is found that these iron ores are developed on about the same scale as coal seams; but that so far as known they do not show at the maximum the continuity exhibited by some of our coal beds, or the thickness shown by many salt beds. The Big Seam of Clinton iron ore in the Birmingham district of Alabama is traceable as a geologic unit for perhaps 50 miles from northeast to southwest,

and has been developed for a width of several miles. Beyond these limits proof is either lacking or indefinite; but we may fairly assume that at one particular time a basin 50 miles long and some 10 miles wide was being filled with iron oxide. This filling amounted to some 30 feet in thickness at the deepest portion of the basin; it may have averaged 10 feet over its entire extent. After allowing for the low grade of much of the ore, the fact remains that some five thousand million tons of iron oxide were laid down in a continuous deposition at one particular place and time. It will be seen that this introduces factors which are absent when small bog deposits are considered.

The Big Seam basin was large, but the tonnage laid down is not by any means unique. The Wabana basin in Newfoundland, so far as can be determined now, probably had a continuous deposition amounting to seven thousand million tons of iron oxide. The Brazilian area may have shown even larger instances of individual deposits; and Lorraine is on almost the same scale.

But we can go much further than this, in two ways. First, almost every district shows not one but several or many ore beds; second, during any given ore-depositing period the general area affected was much larger than is now considered in any single district. As regards the first point, reference to the descriptions of the various districts in Chapters XVIII and XXI will show that they exhibit from three to ten or more ore beds, even limiting consideration to those now commercially workable. As regards the second point, we must consider that the ore deposition during Clinton time in the southern and eastern United States took place over a general area some seven hundred miles in length and at least fifty miles in width. It is, of course, improbable that, at any given moment, ore deposition was taking place simultaneously over all or any large fraction of this area; but the figures will throw some light on the general extent of the problems involved. It can be seen that purely local causes cannot be invoked to explain the origin of ores which occur in such large individual basins, which were likely to occur over such vast areas, and which recurred in such frequent fashion.

Associated Rocks.—It has been noted that the iron-ore beds form one element in large rock series; and that they are associated and interbedded with sedimentary rocks of various types.

In different periods and in different areas the rocks varied considerably, but in at least the Wabana and Clinton series there is a certain amount of similarity in the character of the sedimentation. The most striking features in each case are the abundance of shales associated with the ores, the relative scarcity of limestone beds, and the frequent recurrence of the various types in a thin-bedded series of alternations.

For the following section which illustrates very remarkably both the frequency and the character of the alternations, I am indebted to Messrs. Cantley and Chambers of the Nova Scotia Steel & Coal Co. The section starts some distance above the main or Dominion ore seam in the Wabana trough (Newfoundland), passes through it at one of its thicker phases, and terminates some distance below it. It may be noted in passing that the seam here shows well over 20 feet of clean ore, but at present we are concerned more closely with the way in which thin alternations of shales, sandstone and ore are exemplified by this particular section.

	Feet	Inches		Feet	Inches
Shales	25	3	Shale	0	1
Iron pyrite	0	3	Ore	0	6
Shale	2	0	Shale	0	1
Iron pyrite	0	2	Ore	0	4
Shale	1	3	Shale	0	1
Iron pyrite	0	6	Ore	0	5
Sandstone	4	2	Shale	0	2
Lean ore	0	2	Ore	1	4
Sandstone	0	6	Shale	0	2
Lean ore	0	2	Ore	1	9
Shale and sandstone	1	6	Sandstone, ferruginous	0	1
Lean ore	0	3	Ore	1	2
Sandstone	1	8	Sandstone	0	1
Ore	0	5	Lean ore	0	8
Shale	0	2	Shale	0	9
Ore	7	0	Sandstone	0	4
Shale	0	1	Ore and shale mixed	1	8
Ore	6	10	Shale	1	0
Sandstone, ferruginous	0	2	Sandstone	6	1
Ore	0	4	Shale	0	5
Shale	0	9	Ore	1	2
Ore	0	4	Sandstone	1	8

Instances bearing on the same point could be multiplied to any desired extent, for careful examination of the sections shown

in all of our own Clinton ore districts shows the same type of occurrence.

Related Phenomena.—Among the related phenomena which help to throw some light on the conditions surrounding the formation of these ore-bodies, are the occurrence of fossil organisms, of ripple-marks, and of mud-cracks.

Fossil shells, corals, crinoids, etc., occur not only in the beds associated with the ores, but at times in the ore beds themselves. In this latter case the fossils may be partly or completely replaced by iron oxide; and in some instances the bulk of an ore bed is made up of ore formed in this way. At other times the fossil is merely coated with a layer of iron oxide.

The fossils associated with the ore series are of marine type; and they are not notably different in type and size from examples of the same species occurring elsewhere. The ores must therefore have been deposited in marine basins, and these basins could not have been entirely or steadily cut off from communication with the open sea.

On the other hand, we have direct evidence that the basins were very shallow, and subject to frequent small oscillations of level. The shale beds associated with the ores often show ripple-marks and mud-cracks; and at Wabana the floor of the Dominion seam is similarly marked.

Structure of the Ores.—The marine oxide ores differ greatly in structure in different regions, in different beds, and even in different portions of the same bed. This fact has not been given sufficient attention in the past, and to its neglect are due some of the most interesting controversial writings on the subject of origin. It is perhaps a natural tendency of human nature to assume that the only possible mode of origin is that which the author happens to have studied.

As regards internal structure, we may distinguish a number of general types which we are likely to encounter in any ore field, though some are far commoner and more important than others. There are, commonest and best known, the *oölitic ores*, in which the iron ore occurs as small spherical or flattened forms consisting sometimes of a coating of iron oxide surrounding a central grain of silica; and sometimes a fairly homogeneous oölite of iron oxide with or without silica. The individual oölites are often held together by a cement of lime carbonate or clay. Second in

importance are the *fossil ores*, in which fragments of fossils are replaced by iron oxide. Third in extent, but primary in their

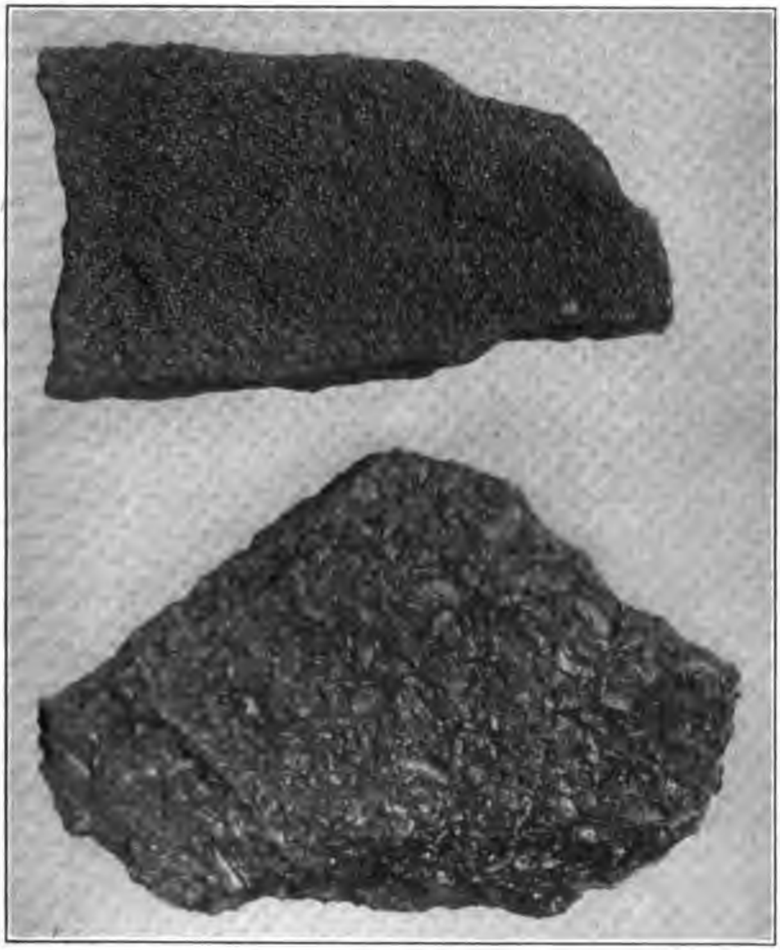


Fig. 5.—Types of Clinton sedimentary hematites.
Upper figure oölitic ore; lower figure hematite replacing and filling between fossil fragments.

geologic significance, we find ores in which the iron oxide is spread merely as a thin coating over a quartz grain or pebble, or in which it occurs as a fine-grained iron mud.

From studies of the two types first named—the oölitic and the fossil ores, several divergent theories of ore origin have been developed. According to one well-known theory, the ores originate mostly by the replacement of fossil fragments on the floor of the basin in which these fragments lay. According to other theories, calcareous or siliceous oölites were first formed, and later these were completely or partly replaced by iron oxide.

Looking at the matter very generally, it would seem fair to suggest that investigators have concentrated their attention upon local and accidental circumstances, and have overlooked the more basal phenomenon. *The element which is universal and persistent is that, during certain periods, iron oxide was actually precipitated from water; the accidental element arises from the material which, in any given place, this iron oxide combined with, coated or replaced.* Sand grains and fossil fragments must occur in every ocean basin, and in attempting to explain the origin of these oxide ores we must seek a more general reason for the heavy precipitation of iron oxide in these particular beds.

Composition of the Original Precipitate.—From the industrial standpoint the point of chief interest is, of course, the actual bulk composition of the ores as they now exist; and this will be discussed in more detail in the later chapters dealing with the local occurrence of the various ores. For the purposes of the present chapter it will be of interest to attempt to form some idea of the composition of the iron sediment as originally precipitated, and before the oölites or granules were cemented together by lime or other foreign matter.

At first sight it might seem as if such a line of inquiry could not possibly give satisfactory results, but on investigation it will be found that many of the difficulties disappear when they are faced, and that the final results are sufficiently close to be very serviceable.

A number of complete analyses of sedimentary oxide ores are on record and some of these relate to ores which, for one reason or another, may fairly be considered as approaching in composition the original iron deposits. The Wabana ores, for example, have relatively little cementing material included in their bulk; while in the southern United States the leached or "soft" ores have been cleared of their cementing matter by natural processes. Unfortunately no Lorraine analyses fit for this use

are at my disposal, and the Brazilian ores can be omitted for other reasons.

ANALYSES OF SEDIMENTARY IRON DEPOSITS

	1	2	3	4	5
Ferric oxide	76.94	75.46	73.53	76.77	73.33
Ferrous oxide	.....	0.10	0.69	0.46	0.19
(Metallic iron)	53.86	51.12	52.11	54.15	51.60
Manganese	0.65	0.31	0.26	0.15	0.23
Phosphorus	0.85	0.47	0.51	0.648	0.22
Sulphur	0.018	0.02	0.11	0.086	0.14
Silica	9.48	7.62	10.97	10.63	16.70
Alum na	3.55	4.31	6.94	5.64	6.62
Lime	1.81	0.40	2.28	2.25	0.27
Magnesia	0.84	0.47	0.73	0.52	0.22
Potash	n. d.	0.30	n. d.	0.17	n. d.
Soda	n. d.	0.13	n. d.	0.01	n. d.
Carbon dioxide	4.32	0.32	0.07	0.09	0.07
Combined water	4.32	9.35	2.96	1.71	1.53

1. Wabana ore, Newfoundland; analysis quoted by Cantley.
2. Clinton ore, Chamberlain, Tenn.; G. Steiger, anal., Bull. 16, Tenn. Geol. Sur.
3. Clinton ore, Rhea Springs, Tenn; 10th Census U. S., Vol. XV.
4. Clinton ore, Attalla, Ala; 10th Census U. S., Vol. XV.
5. Clinton ore, Birmingham, Ala.; 10th Census U. S., Vol. XV.

The analyses presented in the preceding table are surprisingly concordant, in view of the facts that they cover ores of different geologic ages and from widely separated localities. As to their results, it is obvious that carbon dioxide may be disregarded as representing incomplete leaching; and that combined water may also be set aside, as representing recent hydration. The lime, magnesia, soda and potash are small and variable, and are of interest chiefly as negative indications. The sulphur is variable, for as elsewhere explained it is principally confined to certain layers.

The main components of the iron deposit are evidently iron oxide, silica and alumina; which if combined water and carbon dioxide be allowed for, make up together from 93 to 98 percent of the total mass of the ore. They can be regarded as the three

essential constituents. There is no proof that lime carbonate was present originally in oölitic form; if so, it has been removed completely, and was not re-deposited anywhere in the series. So far as we can judge from this line of investigation, the original deposition was in the form of a finely divided iron oxide, chiefly precipitated from solution, which in its descent trapped and carried down with it a certain amount of finely divided clayey matter.

Local conditions determined the details of the process and of the results. In some places the descending precipitate fell upon masses of shell fragments, which it coated or replaced; in others it coated sand grains; in a few basins it may have taken a truly oölitic form or have replaced earlier oölites. As to the physical, topographic and chemical conditions which caused or favored such exceptionally heavy precipitation of a fairly pure iron oxide the proof must be sought in other directions.

Summary of Relations.—Having discussed various phases of the structural relations and associations of the basin ores in detail, it will be well to summarize the matter before going further. In examining the ores of any particular age and district we commonly find that the general area of ore deposition has been very large, and that even the individual ore beds are sometimes very thick and extensive. Further than this, there are commonly a number of ore beds scattered through the rocks of the ore-bearing series. These ore beds are separated by, and associated with other rocks, which frequently occur in thin alternations. These accompanying rocks are predominantly fine-grained shales; sandstone and limestone also occur, but much less frequently than shale; and there is usually more sandstone than limestone. The entire series may make up several hundred feet in thickness, and through it the shales are usually higher in iron than ordinary clays and shales; and the sandstones are commonly ferruginous to a marked extent. The entire series therefore marks a period during which all the deposits were of high iron content, and during which at recurrent intervals beds of exceptionally high iron content—the iron ores—were laid down.

Marine fossils occur in all the rocks, and even in the iron ore itself. The shale beds often show ripple-marks and mud-cracks; and in places the floor of an ore bed shows similar markings.

The ore itself may be of truly oölitic type, it may be a ferriferous coating on sand grains or quartz pebbles, and in places it is a filling or replacement of fossils. It is normally high in phosphorus and rather high in sulphur. It is also commonly higher in alumina, as compared with silica, than are most other iron ores. When a layer of iron pyrite occurs, it is not in the middle of an ore bed, but at its top or bottom. There are practically no nodules of pyrite, or of unaltered iron carbonate, within the ore beds.

All of these facts must be taken into consideration in attempting to formulate any adequate theory of origin for the marine oxide ores.

The Question of Origin.—The facts in the case having been separately stated, it remains to be seen whether or not they will, considered together, throw any light on the origin of the marine deposits of oxide ores. By keeping strictly to the general conditions, and avoiding purely local and accidental phenomena it seems as if some progress might be made in that direction.

There are obviously several factors which must have co-operated in order that an ore deposit could be formed, possessing the associations, the structure and the composition which have been described as occurring in most of the deposits of the class under consideration. Put into the most general wording, there must have been a supply of iron in solution, an agency which caused its precipitation, and a favorable place for the deposit to form. For convenience these three factors will be considered in the reverse order to that in which they have just been named.

(1) The structural relations of the deposits, and the character of their associated rocks, imply that the deposition must have taken place in long, narrow basins, probably parallel to the coast-line, generally shallow, subject to frequent oscillations of level; and probably at least part of the time entirely cut off from the access of sea-water.

(2) In a basin of the type described dissolved iron compounds would be carried by the sea-water; and additional supplies might be derived from streams feeding directly into the basin from the landward side. The water of the basin probably carried more iron than average sea-water of the present day, for otherwise sufficient evaporation to produce iron deposits would normally have resulted in a concurrent or later deposition of other salts.

But, on the other hand, we can not assume that at the outset these basins were filled with a very rich iron solution, for the character of the fossils does not bear out that conclusion. Further than this, we must allow for the possibility, which in some instances seems to be almost a certainty, that in part at least the iron oxide was present in suspension as a fine-grained iron mud.

One additional fragment of evidence may be noted. The clayey matter which was precipitated with the iron oxide, as well as the shaley material which is interstratified with the ore beds, has certain points of interest. In general all of these clayey sediments seem to be somewhat higher in alumina and iron, and lower in silica, than normal shales and clays. They can hardly have been derived from freshly weathered granitic or similar rocks, but point rather to derivation from deeply weathered limestones or basic igneous rocks. If the latter, the relative scarcity of limestone earlier in the ore series is remarkable, for the weathering of fresh basic rocks would certainly yield an abundance of lime in solution. So, in the last analysis, we come to the conclusion that there is no absolute necessity for postulating concurrent igneous activity of any sort, though that may well enough have occurred. The more probable source of both the iron-charged waters and the fine-grained clayey sediments was from a low-lying, deeply weathered land surface, draining down to a shallow sea.

(3) Whatever the character of the water may have been at the outset, some agency was available which sufficed to precipitate the iron in the form of oxide. So far as the history of the deposits can be made out from the sedimentary record, the agency most likley to produce this effect was evaporation of the basins, at least to the point of iron deposition. We do know that the basins were dried at intervals, and then refilled; so that iron ores are covered by shales and sandstones. After each period of partial or complete dessication there was a submergence, a temporary cessation of iron deposition, and a deposition of (usually) fine-grained clay or (more rarely) fine sands.

It is, of course, possible enough that organic matter played some part, in some areas, in the matter; and that locally the composition and character of the iron deposits may have been seriously influenced in this way. In places there was undoubtedly replace-

ment by iron oxide of shell matter on the sea-bottom; at other points or in other periods there may have been deposition of the glauconite type; it is even possible that replacement of originally calcareous oölites may have occurred in some ore basins. But, after all, these are merely secondary and local phenomena. Such infiltrations and replacements could not have taken place unless an abnormal iron supply were present.

Two widely variant types of Clinton ore, differing greatly not only from each other but from all commercial ores, may be noted as tending to throw some light on what extreme products could be made in the Clinton seas. One occurs in West Virginia, where we spent considerable time in tracing back some very remarkable float ore. When the original location was discovered, the ore was found to occur in several very thin beds, with no reason to believe that they had been formed except as sediments, and with no trace of later alteration and enrichment. They were unworkable, for the thickest bed was only some 8 inches, and the total thickness of the several beds did not amount to over a foot. But the ore itself was a steely blue hematite, grading from 60 to 65 percent metallic iron, and well below the Bessemer limit in phosphorus. At the other extreme of the series we may place certain beds in the Clinton rocks of eastern Alabama, where quartz pebbles up to several inches in diameter are coated with relatively pure iron oxide. It will be seen that the one instance suggests that a very pure and concentrated iron solution was available in some basins; the other, that organic action, oölites and fossil fragments were not *necessarily* a part of the process.

Typical Deposits.—The iron-ore fields of the world offer three examples of iron oxide deposition on a truly enormous scale, with a possible fourth example of even greater extent. The three well-determined examples are the (1) Clinton ore deposits of the eastern and southern United States; (2) the minette ore deposits of the Lorraine-Luxembourg area in Europe, and (3) the Wabana basin of Newfoundland. The fourth doubtful example, according to some views, would be the Brazilian area.

Of the well-known examples, the original deposition left workable commercial ores in the three cases cited while in the Lake Superior district the ores as originally deposited were too lean to be commercially available, but through subsequent natural concentration these original lean ores have given rise to workable deposits.

The amount of iron involved in these great basin deposits is very large. I have shown elsewhere, for example, that in the southern United States the Clinton beds contained a total of over 86 thousand million tons of ore, equivalent to over 26 thousand million tons of metallic iron. If all of this iron were derived from the leaching of rocks whose iron content corresponded to that of the average earth's crust, as now known, over eight millions of millions of tons of rock must have been decomposed to furnish the iron finally deposited in this part of the Clinton series.

Similar calculations for the Luxembourg basin give results of about the same degree of magnitude, while the Lake Superior and Brazilian basins would give far higher totals. The supply of the material necessary for these great basin deposits therefore involved geologic work on a vast scale. But, further than this, it also involved great rapidity in the rate of this work.

CHAPTER VI

REPLACEMENTS AND FILLINGS

In this group are included such iron-ore deposits as have originated through the deposition of an iron mineral in a pre-existing rock mass. The iron is always brought to its point of deposit in solution, but many variations are shown in the various stages of this process. For example, the iron-bearing water may be ascending or descending, heated or cold; the deposition may take place in pores or cavities, or usually by actual replacement of the rock mass; the process may be incidental to igneous action, or entirely independent of it. It would be possible, taking advantage of these variations in the details of the process, to subdivide this group into an infinite number of sub-classes. The simple grouping shown below, however, seems to cover all actual requirements.

Disregarding possible but unimportant variations, four subgroups of Class C are to be distinguished;

1. *Cavity and pore fillings;* in which pre-existing spaces in a rock mass are filled by the deposition of an iron mineral.

2. *Normal replacements;* in which a mass of pre-existing rock is actually replaced with an iron mineral, deposited from solution independent of igneous action.

3. *Secondary concentrations;* in which a low-grade ore is enriched by iron derived from the upper portions of the ore bed itself.

4. *Contact replacement;* in which a mass of pre-existing rock is replaced with an iron mineral, deposited from heated solutions set in action by local igneous intrusions.

From an industrial standpoint, replacement deposits rank next to the sedimentary deposits in importance, for they include the Lake Superior hematites, most of our eastern and southern brown ores, and many brown ores, hematites and magnetites elsewhere in the United States and abroad.

1. Cave and Cavity Fillings

Rock-masses of any type or kind may contain cavities of greater or lesser extent, even if nothing more than spaces widened out by solution along joint planes. Limestone, however, is peculiarly subject to attack by even slightly acid waters, and by far the majority of large open cavities or caves occur in limestone. Waters penetrating from the surface, and charged with carbon dioxide or other acid agent, readily dissolve out channels and chambers in the rock.

This much being generally accepted, it is obviously conceivable that other waters, carrying iron carbonate or other iron salt in solution, might refill such solution cavities with a deposit of iron ore; and this possible mode of origin has been given consideration in various published discussions on the formation of brown iron-ore deposits. Evidence in its favor is, of course, afforded by the frequent occurrence in brown-ore deposits of stalactites and other curiously shaped masses of brown ore, which could hardly have assumed these particular forms except in an open space of some kind.

In the writer's opinion it is easily possible to lay too much stress upon this particular mode of brown-ore origin. It is undoubtedly true that brown-ore deposits can originate in this way; it is also true that in almost all of our brown-ore deposits a certain amount of such cavity filling has taken place: but it is highly improbable that any large deposit at present worked has originated entirely or principally in this way. Replacement has been a far more important method.

In spite of frequent discussion of cavity filling as a mode of genesis, no published accounts of the actual formation of iron ores in caves have ever come to the writer's attention. Under these circumstances the following account of a small ore deposit still in progress of formation may be of interest. It is prepared from notes made at various intervals some years ago, while engaged in development work in the iron region lying along the Chesapeake and Ohio Railroad in Virginia.

The old fluxing quarry of the Lowmoor Iron Company, near Lowmoor station, is located in flat-lying limestone beds belonging to the upper portion of the Helderberg or Lewistown series. It was worked in great rooms or chambers, carried up to a roof of

Oriskany sandstone, which in turn is overlain by black Devonian shales. The sandstone is firm, but fairly porous; the shales contain a rather high percentage of iron, in the form of carbonate nodules, or pyrite, and of oxide.

During operation the quarry rooms at several points broke into old water-channels and caves, varying greatly in size. One of these was, at the time of my study of the district, filling with a deposit of brown iron ore. The deposited material was derived from infiltrating waters, which had become charged with iron carbonate during their downward passage through the black shales above the quarry.

Water enters this particular cave at several points, either percolating through the strata or flowing through small channels dissolved out of the limestone. This water carries various materials, some in solution and some in suspension, and the different products of deposition are of interest.

One of the larger channels, for example, brought into the cave a large amount of very fine clayey matter, carrying it of course entirely in suspension. This clay was spread out as an even deposit over the floor of the cavity. Samples which I took were analyzed by Mr. J. H. Gibboney with the following results:

ANALYSIS OF CAVE CLAY, LOWMOOR, VA.

Silica	55.64 percent
Alumina	23.80
Ferric oxide	6.18
Titanic oxide	0.10
Lime	0.52
Magnesia	0.54
Soda	0.51
Potash	5.20

This analysis corresponds quite closely with a number of analyses of the unaltered black shale; and the cave clay has probably been subjected to relatively little change during its transportation and deposition.

The waters seeping through the strata, having been filtered fairly free from all suspended matter, give deposits of strikingly different character from the clay just mentioned. The seepage waters carry iron carbonate in solution and this is deposited where the waters encounter air and free space on entering the cave. The deposition takes place in two distinct forms: (1) as an ochre-

ous powder or mud, sometimes aggregated into hard lumps, on the cave floor, and (2) as iron stalactites hanging from the roof of the cave. Samples of these iron deposits analyzed by Mr. Gibboney gave the following results:

ANALYSES OF IRON STALACTITES AND OCHER, LOWMOOR, VA.

	1	2	3
Metallic iron	46.88	54.56	29.84
Metallic manganese	1.12	0.49	4.16
Silica	5.40	6.29	24.46
Alumina	11.87	5.45	9.10
Lime	0.24	0.16	0.20
Magnesia	0.24	0.33	1.28
Sulphur	0.05	0.03	0.06

Of the above analyses, No. 1 represents the composition of the iron stalactites hanging from the cave roof; and No. 2 is the average of several lumps of the hard ocher formed by deposition on the floor of the cave. Both of these, it will be noted, are very good brown ores, far above the average commercial ore of that district, and comparing favorably with any of the better class of eastern or southern brown ores. Sample No. 3 is of fine ocher mixed with the cave clay; and might perhaps be accepted as representing the average of the material with which the cave would finally be filled, provided the two classes of deposits should keep coming in at about their existing rate.

Certain irregularities in the analyses may be noted—the high manganese determination in No. 3 and the high alumina value in No. 1. The first of these requires little comment, for the presence of even a small nodule of manganese oxide in the sample would account for it. The high alumina of No. 1, however, is more noteworthy, for if confirmed it implies that the stalactites contain, in addition to brown ore, bauxite or some related aluminum hydroxide.

The preceding description of a cave deposit in actual process of formation is of interest chiefly as throwing some light on the difficulty of discriminating deposits formed in this manner after the process has been completed. It is obvious that, given sufficient time, a commercial deposit might easily be developed in this way. Its ores would agree closely in composition with any which might have been formed by direct replacement in the same series; and the only clues to the method of origin would have to be

sought in the form of the deposit and the physical make-up of the ore. A deposit of moderate size, with irregular roof and sides but a fairly level floor, especially if occurring in a flat-lying limestone series, might reasonably be suspected of having originated as a cave or cavity filling. If the ores were entirely iron oxides, with no trace of iron carbonate, even near the limestone contact, this suspicion would be strengthened. If, in addition, stalactitic forms of iron oxide were very common, the proof would approach certainty. Almost every brown-ore deposit, whatever its origin, contains a few stalactites, but extreme frequency of this form would point toward cave origin for the entire deposit.

Origin in this manner has been ascribed to many iron-ore deposits, but the proof is in general inconclusive so far as large deposits are concerned. At present the hematite deposits occurring in Dent, Crawford and other counties in southeast Missouri are the most important deposits whose origin is thought to be of this general type. Crane, in a recent report,[1] describes these deposits in detail, and considers that they are due to the alteration of iron sulphide, originally deposited in limestone sinks.

2. Normal Replacements

In distinction from the class of deposits which has just been discussed, replacement deposits originate not by the filling of a pre-existing cavity, but by the actual substitution of an iron ore, particle for particle, for the body of an existing rock-mass. In the commonest case, iron-bearing waters percolating through limestone remove the calcium carbonate in solution and deposit their iron in its place, usually in the form of iron carbonate. In less common but still important cases, sandstones and other siliceous rocks are similarly replaced by iron ores.

The iron mineral, as deposited, may be carbonate, sulphide or oxide; but subsequent alterations will usually change its mineral character without any change in the form of the ore deposit. As now found, the bulk of our normal replacement deposits occur as brown ores, though hematite deposits of this type are fairly frequent and magnetite deposits are known.

[1] Crane, G. W. The Iron Ores of Missouri, Vol. X, 2d series, Reports Mo. Geol. Survey, 1912, Chapter VI especially.

When the rock enclosing the ore deposit is limestone, there is quite a sharp and definite distinction between cavity fillings and replacements, for the solution of limestone usually results in complete removal of the mass of the rock. But it is different when a porous sandstone (or a sandstone or shale in which the siliceous matter is held together by calcareous cement) is the subject of attack. For in this case the distinction between pore filling and replacement is very indefinite, and the two processes merge into each other very gradually. Certain of these differ-

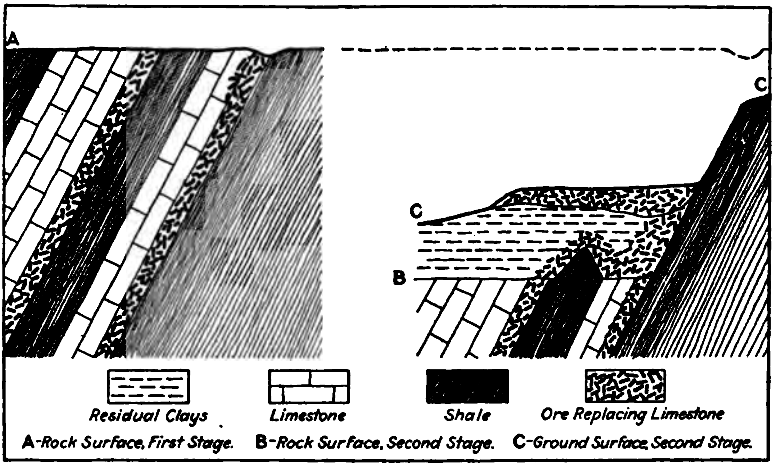


FIG. 6.—States in origin of brown-ore deposit.

Figure at left shows first stage, in which replacement of limestone beds has given rise to tabular steeply dipping ore-bodies. The figure at right shows effects of later weathering of these ore-bodies, the final result being irregular surficial deposits underlain in depth by the replacement beds.

ences arising from the original character of the replaced rock have a commercial as well as a geological importance, and from either point of view they will justify further discussion.

Living in the temperate zone, we become insensibly accustomed to certain types of rock decay, and it is difficult to realize that over the greater extent of the earth's land surface the conditions as to weathering are very different. In the northern United States, for example, we find that limestone is extremely soluble, while siliceous rocks are extremely resistant to solution by percolating waters. All of our recent northern brown-ore deposits are seen

to be replacements of limestone, with practically no trace of attack on sandstones or igneous rocks. But as we go southward conditions change in this regard. Even in Virginia we find sandstones beginning to show replacement by iron oxide, and in Georgia the siliceous rocks contain some notable ore deposits. Further south this change in relative solubility becomes still more marked, and it has important results on the formation and localization of ore deposits.

Relations to the Ground Surface.—Since normal replacements have been formed mostly by waters acting from the ground surface downward, the deposits have a very definite relation to the surface as it existed at the time of their formation. It may further be noted that in actual practice we have only to deal with very recent replacements, originating during a period in which the topography was not markedly different from that shown at present, for replacement deposits of older date would by this time have been removed, covered up by later deposits, or rendered unrecognizable. It is only in very rare cases that we find an ore deposit representing pre-Tertiary replacement.

Owing to those conditions, the replacement deposits actually worked are commonly largest and richest at or very near the ground surface, and they become smaller with depth and finally terminate in barren rock at no great depth. In the Oriskany district of Virginia, where conditions have been exceptionally favorable to deep replacement in steeply dipping beds, the deepest deposits known are in the neighborhood of 600 feet below the present surface; the bulk of the ore of the district has been mined within 300 feet of the surface.

Extent of Deposit.—Replacement deposits of course vary greatly in their continuity, size and tonnage, but where circumstances have been favorable individual ore-bodies are oftentimes far larger than is generally understood. A few instances, covering actual conditions in known ore-bodies, may be of interest in this connection.

The ore-body worked at the Oriskany mine in Virginia, which is a practically continuous deposit of the replacement type, has been estimated to contain some six million tons of ore. At the Rich Patch mines, in the same district, there have been surface and underground workings on one absolutely continuous ore-body 5600 feet in length, with an average of 400 feet or more in

depth, and of 35 feet in width. This corresponds to from three to four million tons of commercial (washed) ore in the individual deposit.

When the inquiry is extended so as to cover the entire area within which replacement has been common, the figures are of course on a larger scale. In the Oriskany district of Virginia and West Virginia, for example, there is an area some 100 miles or moreint length, and from 20 to 30 in width, within which almost every mile of Helderberg limestone outcrop will show some replacement by iron ore. The entire group of deposits thus formed may easily contain over 100 million tons of ore of various grades.

Form of the Deposit.—The form taken by a replacement deposit is to some extent dependent on the character of the rock replaced, but to a larger degree depends on the attitude of the bedding in the original rock.

Other things being equal, a replacement deposit will assume a tabular form, parallel to the rock bedding, when that bedding dips at a high angle to horizontal. In this case percolating waters are apt to pass quite readily down a particularly permeable bed, so that the bulk of the solution and replacement are apt to occur within that particular bed or layer. We thus obtain finally ore deposits having considerable extent along the outcrop, a relatively narrow width across the beds, and a depth much greater than the width but usually less than the outcrop length. This type of deposit is well exemplified by the Oriskany brown ores of Virginia, which have originated by replacement of a steeply dipping limestone bed.

When, in place of a steeply dipping rock series made up of beds varying in solubility, we have to deal with a flat-lying series, or a very homogeneous series, the results as to form of deposit are far different. In either of these latter cases the paths of the percolating waters are not so sharply limited by particular beds, and the final result is commonly an ore deposit of irregular basin shape, perhaps approximately circular or oval in its plan at the outcrop, but narrowing in both directions with depth.

When the rock attacked has not been limestone, but sandstone or a metamorphic or igneous siliceous rock, the boundaries of the replacement deposit are apt to be much more irregular. There is a tendency to form stringers and offshoots, following joint planes or other relatively non-resistant portions of the rock.

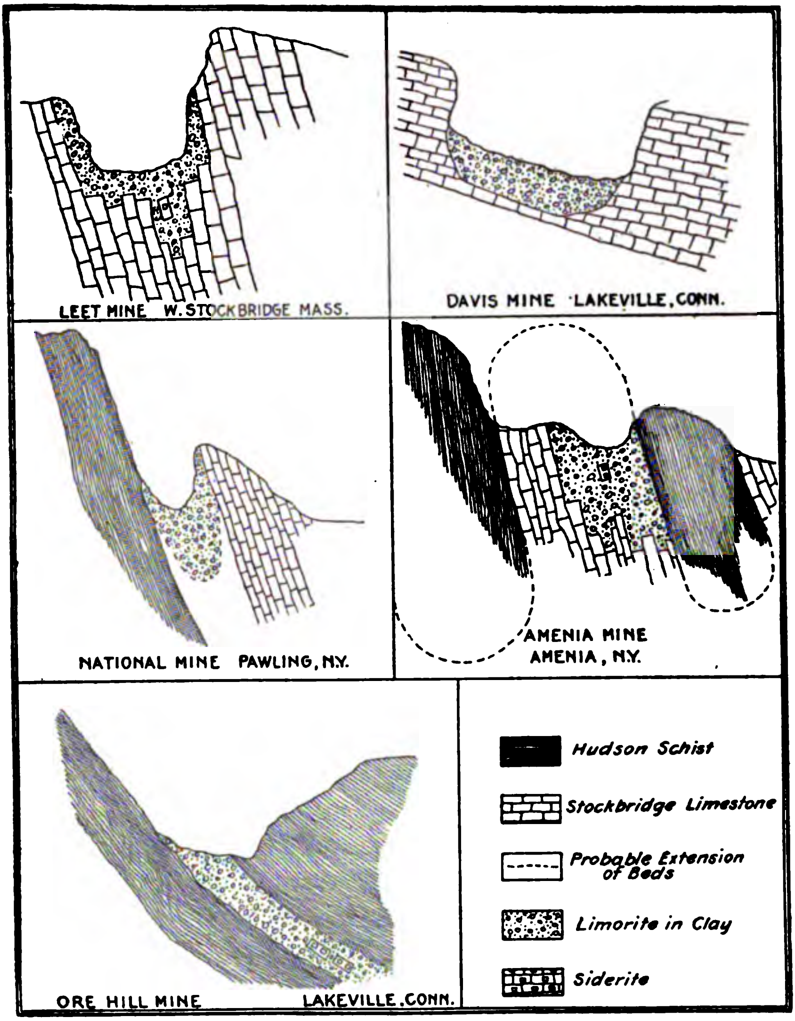


FIG. 7.—Effect of structure on replacement ore-bodies.

These cross-sections of actual ore-bodies in the well-known Salisbury district of New York–New England show the varied effects due to differences in composition and attitude of the replaced rocks. They also show, in some instances, the occurrence of iron carbonate in the deeper levels, a characteristic of brown-ore replacements of limestone.

Composition of the Ores.—At and near the surface the iron ores which have originated by normal replacement are commonly brown ores, though hematite also occurs in deposits of this type. Occasionally the ores do not change in mineral character in depth, but when a limestone has been the rock replaced we are apt to find some of the original iron carbonate at and near the base and sides of the ore deposit.

Considered either as commercial materials or as geologic products, the iron ores of a replacement deposit usually contain constituents from two different sources. Part of their components came in with the percolating iron-laden water; in this class we may include the iron of the ore, and usually most if not all of the manganese, sulphur and phosphorus it may carry. But there is another and often very important part of the existing ore which does not represent material carried in by the water, but material left behind during the solution of the rock which has been replaced. Thus the ore may contain fragments of chert or flint, left behind by the solution of cherty limestone; it may contain sand grains, residual from a replaced sandstone; or it may carry clayey matter, usually left behind by a replaced limestone.

Later Weathering.—The Oriskany brown ores of Virginia, which have been discussed as typical examples of replacement deposits, were selected for such treatment because in this instance all of the geological elements entering into the problem are fairly well known; the extensive workings have supplied adequate data as to form and composition; and, most important of all, in this particular district the effects of later weathering have not been such as to modify or conceal the real relations of the ore to its enclosing and associated rocks.

In this last regard the Oriskany ores are somewhat exceptional among Southern brown ores, for most other districts have suffered greatly from weathering and decomposition of the rocks subsequent to the formation of the ore deposit.

Chief Typical Deposits.—From the standpoint of tonnage and industrial importance, the ore deposits of this type include a number of interesting examples. Among these may be noted the Oriskany brown ores of Virginia, the English hematites, the hematites and carbonates of north Spain and southern France, and the hematites of the Santiago district in Cuba. These are

described in later chapters where additional local details concerning the characters and relations of normal replacement deposits may be found.

It is highly probable that almost all of the brown ores of the southern and eastern United States had an origin that is due, in some degree, to replacement. But in most cases subsequent rock weathering has affected the form of the deposit very markedly, and has in some cases introduced ore deposition of another type. As the deposits stand now, it is questionable whether they are due mostly to replacement or mostly to later residual action and re-deposition. When any particular case can be studied in proper detail, it is commonly possible to come to some conclusion regarding this point; but the conclusion relates only to the instance studied, and should not be extended so as to cover brown-ore deposits in general.

3. SECONDARY CONCENTRATIONS

In the normal replacements which have just been discussed, the ore deposit originated by the introduction of iron minerals into a previously barren rock. But it is clear that similar processes could, under favorable conditions, be carried on within a bed of low-grade iron ore; and that they might ultimately result in such concentration of the iron as to render a portion of the bed workable. It is with deposits of this type that we have now to deal. As it happens, this class of ore deposits includes one of the most important series of iron ore deposits in the world—the hematites of the Lake Superior region. It also includes some less well-known examples, among which the Hartville ore deposits of Wyoming may be noted.

Extent of the Deposits.—Since the formation of secondary concentrations implies the existence of a low-grade iron deposit, it is obvious that the extent of the secondary deposits must be limited by that of the pre-existing low-grade ore-bodies. In discussing the sedimentary iron ores, it was noted that there are vast deposits of iron silicates, carbonates and oxides, deposited in extensive marine basins, and formed during various periods in the earth's history. If secondary concentration should take place in a series of this type, it is evident that the final results might be remarkable, both as regards the general areal extent

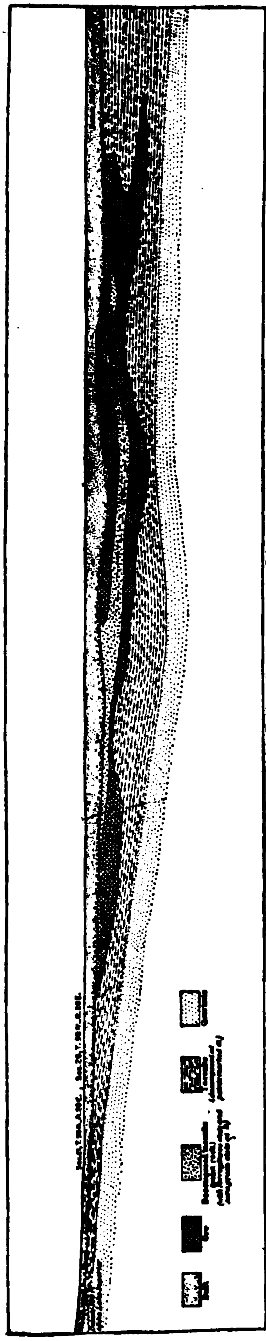


Fig. 8.—North-south cross-section through iron-bearing Biwabik formation, Mesabi district, Minnesota. *After O. B. Warren and C. K. Leith, U. S. Geol. Survey.*

of the ore field and the size of the individual deposits. In the Lake Superior region we have an instance of this sort, where under favorable conditions as to later concentration enormous bodies of low-grade iron mineral were acted upon with the result that the final products—the existing ore deposits—are on a very large scale.

Relations and Importance.—Secondary concentrations are not in any sense common sources of iron ore deposition, but they have an importance far out of proportion to their frequency, due solely to the fact that the Lake Superior ores are now usually assumed to have been formed in this manner. This one large-scale example tends to throw the process of secondary concentration into a relief to which it would not be otherwise entitled; for with the exception of the Sunrise or Hartville ore deposits of Wyoming no other large iron ore-bodies have been attributed to this method of origin.

Though discussed here as closely related to normal replacements, it is readily seen that secondary concentrations have at least equally close relations with two other classes of iron deposits—the sedimentary and the alteration or residual deposits. Their relationship to the first class arises from the fact that the formation of extensive low-grade sedimentary iron deposits was the first

step in the origin of the existing Lake Superior concentrations. Their relationship to the alteration or residual ores is perhaps even closer, for the two classes differ chiefly with regard to the transfer of iron during the alteration processes. In dealing with the formation of gossan deposits, the conversion of hard Clinton ores into soft or leached ores, and the surficial alteration of iron carbonate into brown ore, it will be seen that the initial processes are of much the same type as take place in the case of the secondary concentrations. But in these latter the iron is removed and

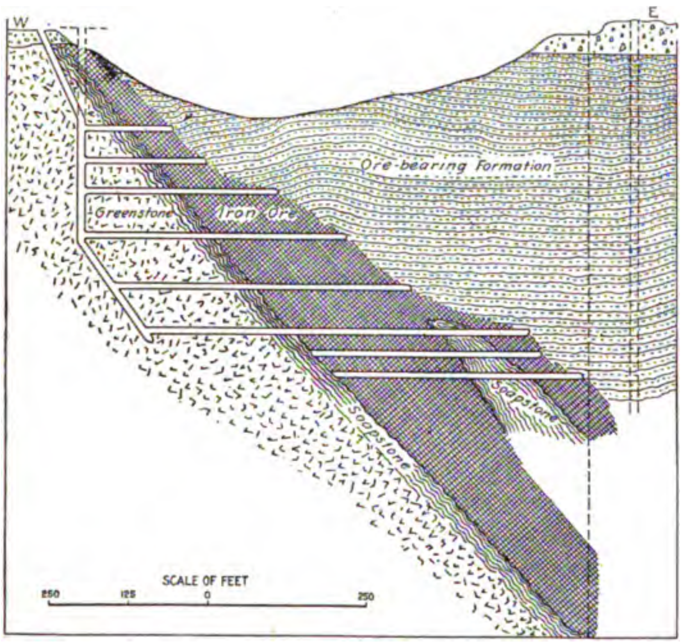


Fig. 9.—Vertical east-west section through the Chandler mine, Vermillion range, Minnesota. (Clements.)

redeposited by replacement in another part of the same bed or series, while in the residual ores the non-ferrous constituents of the original body are removed, and the iron left practically unchanged in position, though altered in mineral character.

Requisite Conditions.—In the formation of an important body of iron ore by secondary concentration, certain factors must cooperate in a very complete and extensive fashion. The absence

of any one of these factors, or their failure to co-operate in the proper space and time relations, will prevent the formation of a large deposit of this type. It is this complexity of origin, this necessary delicate adjustment of the contributing factors, that explain the relative scarcity of secondary concentration iron districts.

The factors involved may be summarized as follows: There must be an extensive series of low-grade iron ores, and this almost inevitably involves the preliminary formation of these low-grade deposits by sedimentary means. The low-grade deposits, after formation, must be exposed to leaching, under such structural, topographic and chemical conditions that the iron leached from the exposed portions of the beds is not carried off into the general circulation but is redeposited lower down in the same series. The exact points at which such redeposition occur, and the form which the secondary deposits may take, are further determined by structural or other conditions which may restrict or localize the iron-laden water.

It can be understood that in the vast majority of cases, assuming that an upturned series including some low-grade ore beds were leached, one of two results would happen, and that neither of these would lead to the formation of secondary concentrations. Either the non-ferrous constituents of the low-grade ores would be removed by the percolating waters, and the iron mineral left as a residual deposit; or if chemical and other conditions were favorable for the solution of the iron, it would be taken into circulation and deposited elsewhere than in the same bed. With deposits of the types which result from either of these occurrences we are very well acquainted. But in order that a large secondary concentration may result, there must be certain special conditions which do not commonly occur at the same time. Not only must the general structural, topographic and chemical conditions be favorable at the outset of the process, but there must be a very delicate balance between solution and redeposition; and this delicate adjustment must be maintained over long periods of time. In view of these necessary conditions, it is not a matter for surprise that the Lake Superior ores stand almost alone in their assumed mode of origin.

The geologic relations and mode of origin of the Lake ores will be discussed in more detail in Chapter XVII.

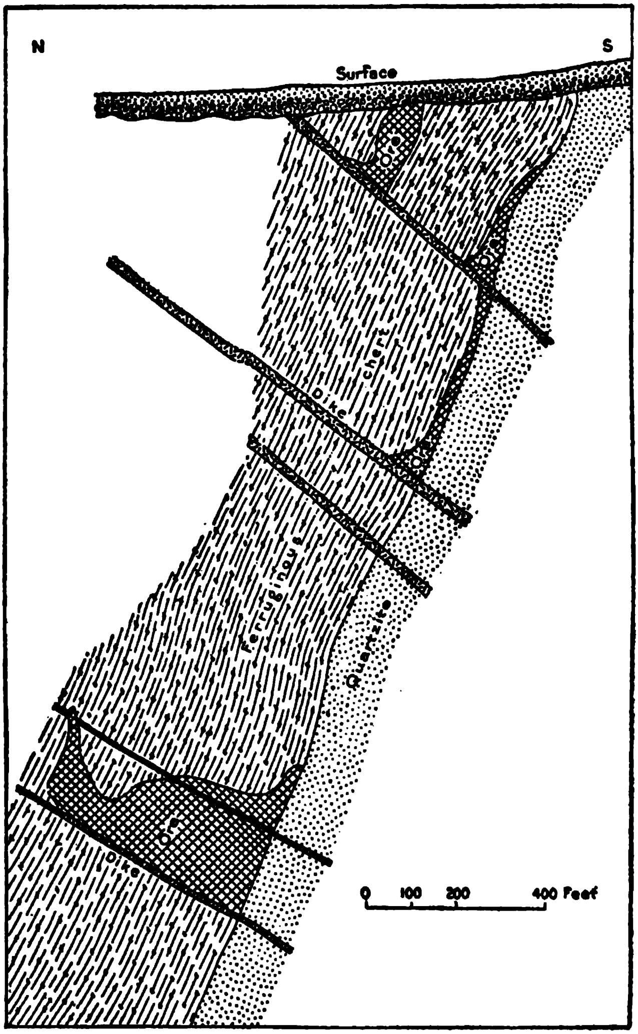


Fig. 10.—Cross-section of ore-body in Marquette district, Michigan. (Leith and Van Hise.)

Secondary concentration of the iron originally contained in the ferruginous chert formation has taken place, the ore-bodies being localized chiefly along the footwall quartzite, or above cross-cutting igneous dikes.

4. Contact Replacement Deposits

When a fused mass of igneous rock is intruded into another series of rocks, heated solutions and vapors emanating from the fused rock may cause various chemical and mineralogical changes to take place, particularly of course in the immediate vicinity of the igneous contact. Ore deposition is one of the possible results of these activities, and many magnetite and hematite deposits have been ascribed to this class.

When iron ore deposition is a result of the processes above outlined, the deposit formed may (1) replace portions of the pre-existing rock through or into which the igneous mass was injected; (2) replace portions of the igneous mass itself; or (3) form fairly distinct veins or joint fillings. Of these three types of resulting deposit, the first is the most common.

Location and Form of Deposit.—Limiting consideration for the moment to the case in which replacement and not vein filling is the result, it may be said that contact deposits may show considerable variation in both form and location, according to the local conditions under which they were formed. Normally the

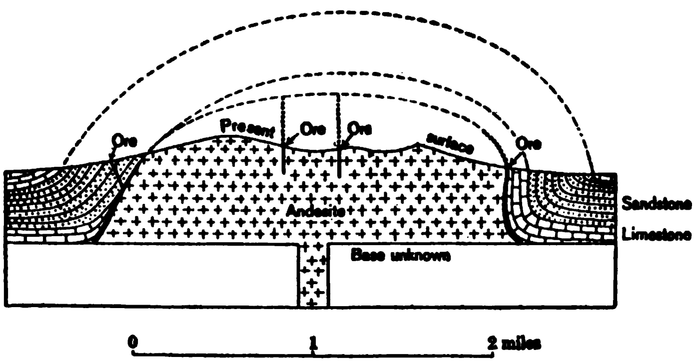


Fig. 11.—Relation of contact ore deposits to igneous mines, Iron Springs district, Utah. (Leith and Harder.)

bulk of the deposit will occur as an irregular mass, lying approximately parallel to the contact between the igneous mass and the older rocks which the igneous mass has penetrated. But when these older rocks are bedded, and there is great variation in the

composition and permeability of the different beds, there is a chance that the iron-bearing solutions or vapors will be most effective *along* the bedding of a readily attacked layer or bed. In this case the final result will be an ore-body of roughly tabular form, extending away from the igneous mass and finally dying out in barren rock.

Contact deposits differ from normal replacements in degree, rather than in any more fundamental way. The igneous mass is effective chiefly as a source of heat, permitting more rapid and effective chemical action than would occur with waters acting at ordinary temperatures. The igneous rocks may also serve, in a subordinate capacity, as sources of part or all of the iron finally gathered into the deposit; but obviously that effect is not markedly different from that produced by any other rock mass. The matter might be summarized by saying that all reactions are likely to be both quicker and more complete under the influence of the igneous heat; and that some reactions which would not occur at ordinary temperatures may take place in contact deposition.

As with normal replacements, limestones are by far the most readily attackable rocks under contact action. When the contact deposit is a replacement of a limestone mass, it is apt to be both larger and more continuous than when siliceous rocks have been attacked.

Chief Known Occurrences.—Iron ore deposits of contact origin are known to occur in many portions of the world, but certain areas are particularly well supplied with them, owing to their geologic history. In the western portion of the United States, for example, practically every large iron deposit between the Rocky Mountains and the Pacific Coast is of this type, the working or partly developed districts of Fierro, N. M., and Iron Springs, Utah, falling in this class. In western Canada the same statement holds true, the best-known examples being the ore deposits occurring on Texada and other islands off the coast of British Columbia. Almost everything so far developed or examined in Mexico and Central America has turned out to be a contact deposit; and the deposits of Chile and other areas along the west coast of South America are similar. We might summarize the matter by saying that almost every known iron deposit along the Pacific Coast, from Alaska to southern Chile, and from the actual

coast back to the easternmost mountain range, falls in the class of contact deposits.

In the eastern United States we have to deal with deposits of greater age, and less certain origin. Spencer considers that the

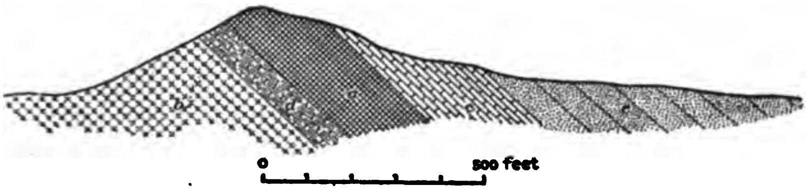


FIG. 12.

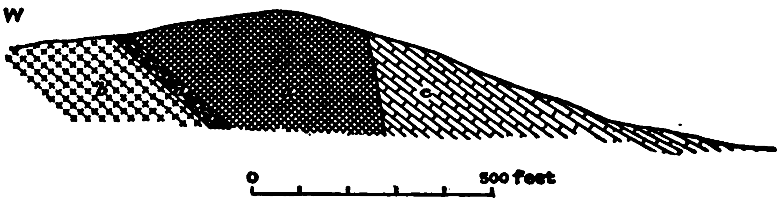


FIG. 13.

FIG. 12, 13.—Contact ore deposits in Iron Springs district, Utah. (Leith and Harder.)

Cornwall magnetites of eastern Pennsylvania are contact ores; and Keith seems to credit the Cranberry magnetites of North Carolina to the same mode of origin. In a somewhat modified

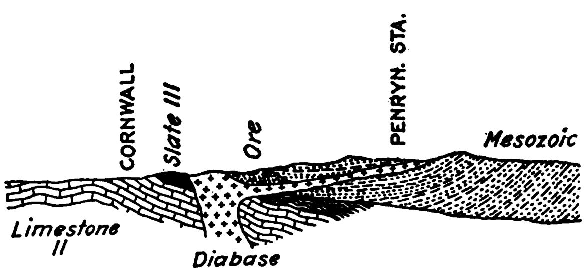


FIG. 14.—Contact ore deposit at Cornwall, Pa. (Spencer.)

form Spencer has applied the same idea to some of the New Jersey magnetites, and it is altogether likely that it could be extended to cover New York ores in both the Highlands and Adirondacks.

CHAPTER VII

ALTERATION DEPOSITS

The various types of sedimentary and replacement deposits which have been discussed in the two preceding chapters differ in many respects, but they agree in that in each case the process of ore deposition involved the formation of a new iron deposit in a new place. In other words, one element in the process was the transportation of the iron, usually in solution, from its point of origin to its place of deposition. We have now to deal with several related types of ore deposits in which this element of transportation is either entirely lacking, or else plays a very subordinate part.

The deposits here grouped together for convenience under the head of Alteration Deposits agree in that they owe their present location, form or character to the fact that a pre-existing deposit of iron mineral has been more or less altered or re-made. The chief factor in the alteration is commonly, as in the sedimentary and replacement ores, surface or sub-surface water; but in the alteration deposits the water does little or no transportation of the iron mineral or iron compound.

It will be found profitable to introduce a further restriction into our definition, and to limit the use of the term Alteration Deposits to those in which a previously unworkable body of iron mineral has been converted, essentially in place, into a deposit of workable iron ore. This definition may seem lacking in precision, but when applied to the iron deposits actually encountered it is satisfactory enough for all purposes. As thus limited certain minor types of altered ores are excluded from the present class. Among these minor though locally interesting types may be noted such instances as the usual alteration of carbonate ores to brown ores at the outcrop, the leaching of the limey Clinton ores to soft ore, the local metamorphism of oölitic hematites to magnetite (as in some Nova Scotia areas) and other changes of similar nature. These can best be treated as purely local phenomena, and not as separate types of ore deposits.

As thus limited, the present group includes such iron-ore deposits as have originated through the chemical and physical alteration and weathering of a pre-existing body of unworkable iron mineral or iron-bearing rock. It differs from all the groups heretofore discussed in that the ore deposits included have undergone material change in composition without material change in place.

Though a number of minor variations in process and results could be used as a basis for closer subdivision, the two chief types of alteration deposits which require recognition are:

1. *Gossan deposits;* in which ores are formed by the alteration of a pre-existing deposit of iron sulphide.

2. *Residual deposits;* in which ores are either left behind or newly formed (in place) during the decay or solution of an iron-bearing rock.

In both cases, it may be noted, the iron ore which results is usually one of the hydrated oxides or brown ores. As will be seen during the discussion, there is a close gradation between the various types of alteration deposits, from the gossan ores through the solution residuals to the laterite residuals; and the separation into sub-classes is based chiefly on the convenience of treatment.

Gossan Deposits

During the slow weathering of a body of pyrite of other sulphide ore, the sulphur is largely removed in solution. This leaves a surficial capping of spongy brown ore, called "gossan." At various points in the United States iron-ore deposits of this type occur, some of which are large enough to be of commercial importance. This is notably the case in southwestern Virginia and in the Ducktown region of southeastern Tennessee.

The Original Minerals.—The two minerals which most commonly give rise to the formation of extensive gossan deposits of brown ore are the iron sulphides, pyrite and pyrrhotite. Of these pyrite, whose chemical formula is FeS_2, contains when pure sulphur 53.3 percent and iron 46.7 percent. Pyrrhotite carries considerably more iron and less sulphur, its formula ranging from Fe_7S_8 to $Fe_{11}S_{12}$; its sulphur content from 39.5 percent to 38.5 percent, and its iron from 60.5 percent to 61.5 percent.

This original difference in the iron content of the two sulphides

has little or no effect on the relative richness of the gossan ores formed from them, for that depends upon the character and amount of the gangue and the completeness with which the sulphides have been decomposed.

The original deposit may vary greatly in several important respects: it may have consisted largely of one of the sulphides, or of a mixture of them; the sulphide ore may have been rich and massive, or a lean body, high in gangue materials; the sulphide ore deposit may have been of igneous, of contact or of other origin; and its form may have been a fairly regular band or lens, or a very irregular pockety mass. All of these circumstances

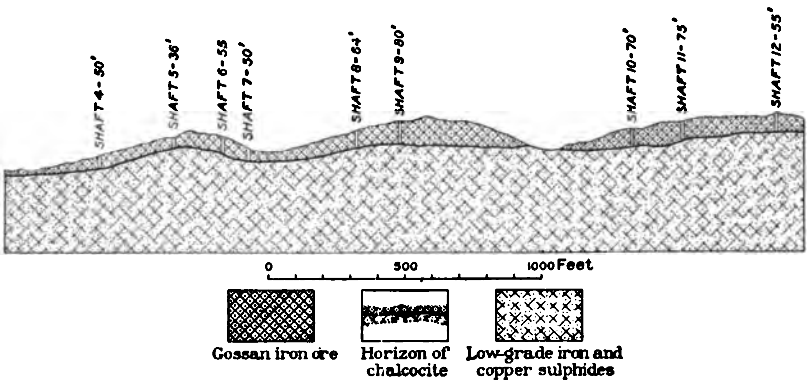


FIG. 15.—Gossan deposits at Ducktown, Tenn. (Emmons and Laney.)

naturally have some effect upon the resulting gossan ore-body; but they are purely local in their nature, and each instance requires separate study and attention.

Process of Alteration.—For convenience it will be well to assume that we are dealing with what is perhaps the most common type, so far as the formation of workable gossan ores is concerned. In this case the original ore-body will be a fairly rich mass of pyrrhotite with considerable intermixed pyrite; the sulphide mass will be enclosed in schists or other metamorphic rocks; and it will be roughly lenticular in form. The entire rock series will dip at a rather high angle, so that the sulphide bodies will outcrop as long narrow bands, varying in width, and at intervals narrowing very markedly or pinching out entirely. When explored in depth these sulphide bands will show considerable persistence,

but also the same narrowing and pinching which they exhibited at intervals along the outcrop. The general effect will therefore be that of a thin lens, or of a series of such lenses, more or less connected.

Atmospheric attack soon decomposes either of the two iron sulphides, and as the general weathering of the district continues,

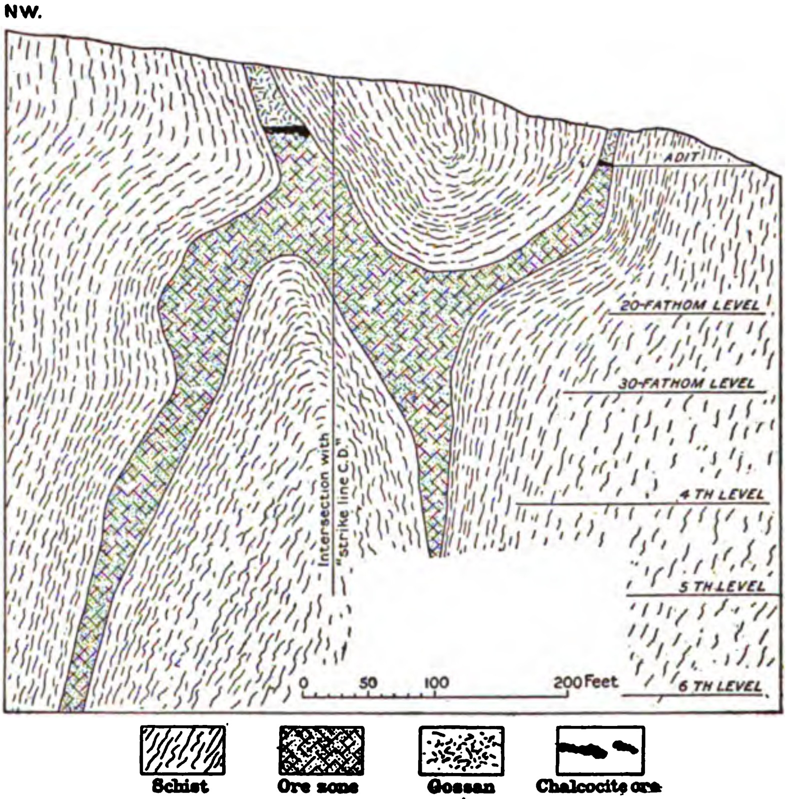


Fig. 16.—Gossan formation in the Mary mine, Ducktown, Tenn. (Emmons and Laney.)

the process of alteration is carried deeper and deeper into the original sulphide mass, until there may be many feet of leached material left as a residual. This residual material will contain most of the iron from the original sulphide, along with whatever quartz or other gangue matter was contained in the sulphide ore-

body. The iron which has thus been left behind during the weathering will be in the form of one of the hydrated oxides or brown ores,[1] and under favorable conditions will constitute a workable iron ore. The process of weathering involves several stages, but the final effect is the formation of sulphuric acid, which is carried off in the waters; and of iron sulphate, which remains behind and alters to brown ore.

Character of the Gossan Ores.—The residual gossan ores are commonly spongy or cellular in character, but this characteristic is not unfailing, and they may in places appear in quite compact and massive forms.

Chemically, they show considerable variations, but there are certain broad features in which there is general agreement. They are commonly, for example, lower in phosphorus and manganese than most other brown ores. On the other hand, when the leaching has not been complete, they are high in sulphur, and often show traces of copper and occasionally nickel. Their iron, silica and alumina contents depend on local conditions entirely, and gossan ores may therefore range from almost 60 percent iron and low silica down to 30 or 35 percent iron with high impurities.

Their value as iron ores depends largely upon the thoroughness with which the sulphur has been removed during the weathering process. When this has been done pretty effectually, the gossan ores are valuable for mixtures, because of their low phosphorus and excellent physical structure. When there is still too much sulphur remaining, it may pay to attempt its removal in a fixed or rotary kiln; but conditions rarely justify this.

Examples and Relations.—The most important single instance of a workable gossan deposit in the United States, from a tonnage standpoint, is afforded by the ores of the Ducktown district in southeastern Tennessee. Next to this in industrial importance are the ores mined at various points along the Great Gossan Lead in southwestern Virginia.

But in other ways the gossan deposits are of still greater interest to the iron industry. They are closely related to other types of iron-ore deposits, and in many cases no hard-and-fast line can be drawn between them. The solution residuals, next to be discussed, will furnish examples of this inter-relationship.

[1] Alteration of pyrite to hematite occurs but not in any quantity under weathering conditions.

Residual Deposits

During the processes of rock weathering and rock decay, some of the constituents of the rock are carried off in solution, while the others remain behind as a mass of residual material. All rocks contain iron, and under favorable conditions enough iron may remain in the residual to form a workable iron-ore deposit. This will depend largely upon the percentage of iron contained by the original rock, upon the form in which this contained iron existed, and upon the conditions under which weathering took place.

General Factors Involved.—The influence of these factors may be summarized as follows:

(1) Other things being equal, the more iron contained in the original rock, the more chance that sufficient iron will be left behind to form a workable residual ore deposit. Stated in this way, it would seem obvious that the basic igneous rocks, or iron-rich sediments, are the most likely to yield residual iron-ore deposits. But the qualification, *other things being equal,* must be borne in mind; and when this is taken into account it will be found that original richness in iron is not the most important factor in the case.

(2) When the iron is present as an oxide mineral—magnetite, hematite, limonite, etc.—it is relatively resistant to solution, and may therefore easily remain in the residual mass. Iron present as a constituent of a silicate mineral, being in the ferrous form, is more likely to be carried off in solution; but even in this case it may be re-deposited before it is moved far from its original location.

(3) Heavy rainfall, heavy plant-growth and an abundant supply of percolating waters—three conditions which normally occur together—favor both the solution and the transportation of iron, whatever may have been its original form of occurrence. If the percolating waters, after being charged with dissolved iron salts, are allowed to escape freely from the residual mass and join an exterior drainage system, there will be no opportunity for the formation of a residual ore deposit. But if such free escape is hindered, the iron may be re-deposited within the residual mass itself, concentrating at locally favorable points.

Certain phases of the matter may now be taken up in more detail, for we are dealing with a very important group of iron

deposits, ranking second only to the sedimentary deposits in their extent and tonnage. It will be best to direct attention first to that type of residual deposit in which the mere removal of the enclosing rock may be considered to have been the most important step in the process of origin.

Solution Residuals.—In the eastern and southeastern United States, and for that matter in many other portions of the world, brown-ore deposits of somewhat uniform type are encountered. They are not bog ores, for they show no evidence whatever of having been deposited in water basins. They are not, in their present form at least, ordinary replacement deposits, for they occur chiefly as masses and fragments of brown ore enclosed by and associated with residual clays. In most cases the mixture of ore and clay is underlain at some relatively shallow depth (20 to 150 feet) by solid limestone, and the ore-body is usually covered by deposits of quite recent sands and gravels.

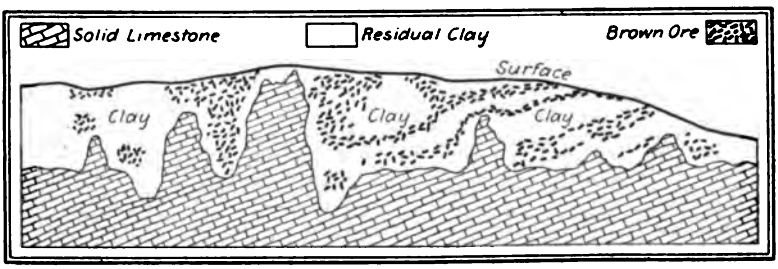


FIG. 17.—Typical residual brown-ore deposit.

In discussing the origin of these deposits it must be premised that the limestones on which they now rest once outcropped at elevations high above the present level and that these limestones have been reduced to their present level largely by simple solution. Water has dissolved and carried off the lime carbonate, leaving behind the clayey matter once contained in the limestones. This residual clayey matter now appears as the sticky clay with which the ores are so closely associated and in which they are often actually embedded.

The following analyses of the limestone associated with brown ore from an Alabama district are of service in the present connection:

ANALYSES OF LIMESTONE AND RESIDUAL CLAY BELOW BROWN-ORE AT HOUSTON MINE

[Analyst, R. S. Hodges, Alabama Geological Survey]

	SiO_2	Al_2O_3	Fe_2O_3	FeO	TiO_2	CaO	MgO	Na_2O	K_2O	CO_2	H_2O
Unweathered limestone.	12.34	1.34	0.77	....	0.11	44.34	2.54	0.24	0.76	35.20	1.87
Weathered limestone.	27.75	6.57	1.62	0.27	0.39	29.69	3.02	0.23	3.53	22.84	4.19
Residual clay.	55.92	25.24	5.10	0.30	1.21	0.10	1.61	0.43	2.48	.....	9.00

An average analysis of the whole series of limestones composing the original formation, if one could be obtained, would undoubtedly show that the average rock is a very impure limestone. Such a rock, when subjected to weathering agencies, would give rise to the formation of thick deposits of residual material, this residual representing the insoluble portions of the original mass. As it is often assumed that this action would of itself give rise to the formation of brown-ore deposits, it is worth while to determine just what would happen in such a case.

Assume a limestone of the following composition:

Insoluble residuum:	
SiO_2	2.5
Al_2O_3	1.0
Fe_2O_3	0.5
	4.0
Soluble carbonate:	
$CaCO_3$	94.0
$MgCO_3$	2.0
	96.0

A horizontal bed 100 feet thick of this limestone, if the carbonates are removed by solution, would evidently yield a 4-foot bed of insoluble residual material. But this would in all probability be a 4-foot bed of clay of about the following composition:

SiO_2	56.25
Al_2O_3	22.50
Fe_2O_3	11.25
Water, etc.	10.00
	100.00

The point to be kept in mind is that this residual will be a clay,

and that the iron of the original limestone will be present in this clay largely in the form of minute particles of iron-silicate minerals or as fine scattered particles of iron oxide. It will not be present as a distinct mass or bed of brown ore. The matter hardly seems to require much discussion, but many theories of the origin of brown ores tacitly assume that the iron of the original limestone appears in the residual mass as brown ore. A theory of this type would of course imply that 100 feet of the limestone above discussed would by its decay give rise to a bed ½ foot thick of brown ore.

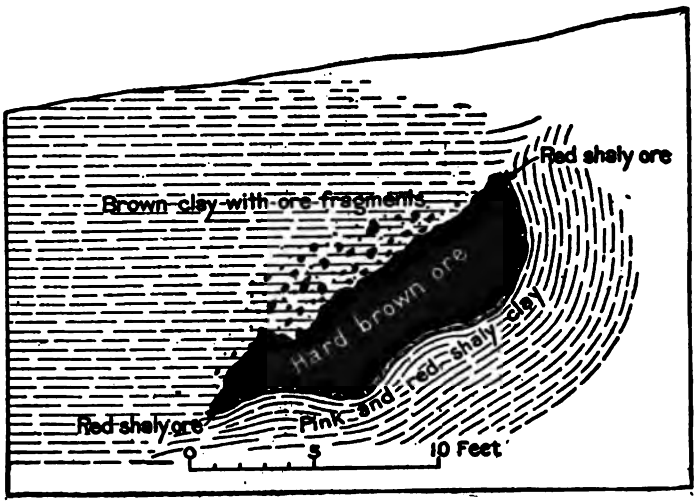


FIG. 18.—Brown-ore deposit, Vesuvius, Va. (Harder.)

It can therefore be set down as an axiom that the decay of a limestone carrying slight percentages of disseminated iron materials can never of itself yield a deposit of brown ore. The decay of the limestone may be a very important step in the formation of such a deposit, but it can never be the only step. There must also be some process by which the iron is concentrated, either in the original limestone or in the residual material. In the opinion of the writer this concentration usually takes place in the limestone before its decay, though in some cases it evidently has occurred in the residual. In the Woodstock district, for example, the bulk of the deposits appear to have been formed by the solution of a limestone in which seams and stringers of brown ore had

been deposited prior to its weathering. In the Russellville and middle Tennessee deposits the evidence is still more conclusive, for in those areas such primary deposits of iron carbonate and brown ore have been found in the unaltered limestone.

In some cases, then, we may conclude that these brown ores were originally deposited as replacements or fillings in a limestone, and that the present deposit is due solely to the removal of the enclosing limestone by surface solution. In other cases there seems to be good evidence that some or all of the brown ore has originated during or after the weathering process took place; so that in addition to the purely residual action there has been actual chemical rearrangement of even the less soluble constituents of the original rocks. Such re-deposition leaves us directly to another important type of residual deposits, which may conveniently be called laterite deposits.

Laterite Residuals.—In discussing normal replacements it was noted that, living in temperate regions, we are accustomed to regard limestone as the only rock which weathers deeply and shows great solvent effects; but that in reality there were certain climatic factors which made this simple rule less useful and finally worthless as the tropical regions were entered.

Clarke has summarized[1] the matter very concisely: "In tropical and sub-tropical regions the processes of rock decay are often carried further than is usually the case within the temperate zones. The leaching is more complete, the silicates are more thoroughly decomposed, and the residues are richer in hydroxides."

It is with the character of these residual materials that we have at present to deal.

It will be seen at once that this is a very important point in connection with the formation of residual iron-ore deposits, for it offers a very wide range of original rocks from which such residual deposits may be formed. So long as we are dealing with weathering as it occurs in temperate climates, we must be prepared to accept limestone as the only rock which can be readily dissolved by surface waters so as to leave an important amount of residual iron. Any other rock would, under normal conditions, leave behind far more silica than iron, so that the residual would be worthless as an ore.

[1] Bulletin 330, U. S. Geol. Survey, p. 417.

But in dealing with tropical weathering, under such conditions that surficial waters can easily remove silica in solution, the case is quite different. A large number of rocks normally contain sufficient iron to yield workable deposits provided the silica left in the residual is small. The more basic igneous rocks, and the serpentine which is a characteristic basic alteration product, contain high percentages of iron, along with other constituents—most commonly silica, alumina, magnesia and lime. Under tropical weathering all of these constituents except the alumina and iron are removable. The resulting residual will therefore contain chiefly brown ore (iron hydroxide), or bauxite (aluminum hydroxide) or more commonly a mixture of both.

As to the rock whose decay furnishes these deposits, it can be said that the brown ores of the north coast of Cuba are residual from serpentine; and that the same is true of some minor deposits in the United States. On the other hand, the bauxite deposits of Arkansas are residual from nepheline-syenite, and some of the foreign bauxites from still more basic massive igneous rocks.

The chief hydrated oxides found in tropical residual material are of course those of aluminum and iron; and the ore deposits which are formed are characteristically highly aluminous iron ores, mixtures of bauxite and brown ore, or even deposits of relatively pure bauxite. Limiting consideration to the deposits in which the iron is the chief ore, it can be said that the ores whose origin is due to processes of this type are characteristically high in alumina, low in silica and phosphorus, usually low in sulphur, and frequently high (for iron ores) in nickel, copper and chromium. All of these features are traceable to the composition of the original rock.

CHAPTER VIII

IGNEOUS DEPOSITS

In discussing contact deposits (pp. 86–88) it was found that igneous action might contribute toward the formation of an ore deposit indirectly, through the heat supply which it furnished, even if the igneous rock did not necessarily furnish all or any portion of the iron. There are, however, large deposits of iron ore which have been ascribed to direct igneous action, and these will be discussed in the present chapter.

The present group includes those cases where iron minerals, in workable quantities, are found as original constituents of a mass of igneous rock. The fact that it is theoretically possible for this to occur seems to exercise a peculiar fascination over the geologic mind, and igneous iron deposits therefore occupy a greater space in the literature of iron ores than is warranted by either their geologic or industrial importance. No iron-ore deposits at present worked in the United States can be ascribed with certainty to this group, though it is possible that some of our eastern magnetites should be included. By common consent most of the titaniferous magnetites are placed in this group.

All igneous rocks, as has been noted earlier in this volume, contain iron as one constituent. Usually their iron percentage is not remarkably high, and the iron does not occur in the oxide form but as a constituent of various silicate minerals. In the more basic rocks, however, iron becomes of more importance; and as its percentage increases there is more possibility that part of it, at least, will not combine with silica but will crystallize out separately as iron oxide, taking the form of either hematite or magnetite. In rare cases masses or areas of igneous rock might be found in which there is enough of this disseminated iron oxide to justify mining and concentration.

Magmatic segregations differ from the disseminated igneous ore deposits in degree of concentration rather than in mode of origin. The principal reason for mentioning them separately lies in the fact that the term *magmatic segregation* has an established and definite status as applied to certain types of sulphide ores.

It is conceivable that during the cooling of a mass of fused rock, the more basic constituents might be separated to some degree from the more acid portions. There would thus arise a segregation within the fused mass of magma itself, and this might reach the point where the basic portion, on cooling, would contain workable deposits of iron ore.

A modification of the magmatic segregation theory requires note, for it disposes of certain of the objections which are based upon the physical relations of the ore-bodies and their enclosing rocks. It is suggested later that it is difficult to reconcile the frequently tabular shape and linear arrangement of ore masses with the idea that they were magmatic segregations. If, however, we assume that the ores were introduced into a slightly earlier and therefore partly cooled magma, some of these difficulties become less important; and this is the ground taken by Stutzer and other who ascribe some of the Scandinavian and other magnetites to formation, not as direct magmatic segregations in place, but as magmatic dikes.

Criteria for Recognition.—It will be worth while, before discussing the deposits which have been ascribed to direct igneous origin, to make some attempt to determine the points in which such igneous deposits are likely to differ from contact deposits or other forms. If any definite criteria for the recognition of igneous deposits can be established, they will of course be immediately serviceable in determining whether or not any particular deposit is of igneous origin. If, on the other hand, it is found that the best criteria available are indefinite or uncertain, this fact also will be of service, as a warning against assigning ores too hastily to the igneous class.

It would seem probable that, if magmatic segregation ever resulted in the formation of a workable deposit of iron ore, this deposit would have something distinctive and suggestive of its origin; and that the distinctions would be related to the kind of rocks with which the deposit was associated, the form of the deposit, the character of its boundaries, or the composition of the ores contained.

As regards the first point, the deposit would of course be associated with igneous rocks, and almost certainly with highly basic igneous rocks. For the chemical difficulties associated with igneous origin, great at the best, become still greater as the parent

rock becomes more acid. If, in the course of field examination, we find a magnetite deposit associated with an acid igneous rock, that fact would tend to bear somewhat against the possible igneous origin of the iron ore, so that the other lines of evidence would have to be a little stronger to make up for this defect. Further, if the deposit is associated, not with certain igneous rocks, but with gneisses whose origin is open to the least question, our conclusions as to the igneous origin of the ore are weakened by just that much.

The form taken by a body of iron oxide segregating from a molten magma would be spheroidal if temperature and pressure

FIG. 19.—Scandinavian ore deposits showing linear arrangement of magnetic ore-bodies. (Stützer.)

were equal on all sides; under actual conditions it would be probably irregular; but there is no serious chance that at the outset it would take the form of a thin sheet, simulating sedimentary bedding. It is true that later metamorphism might squeeze one deposit into this shape, but if we find a series of thin deposits, parallel to each other, the probability is that they are not of direct igneous origin.

As regards its boundaries, it is certain that a magmatic segregation would grade imperceptibly on all sides into the parent rock. If our field occurrence is not entirely enclosed by igneous rocks, but lies along their contact, or if it shows sharp and definite boundaries on foot and hanging walls, it would seem best to seek some other mode of origin.

One of the most convincing of proofs, to which we commonly refer in determining the igneous origin of a rock-mass, is from the

nature of the case not applicable to determining the origin of an iron body. Reference is made to igneous contact effects, both chemical and physical. Except where we are dealing with a dike-like mass of ore, the presumed magmatic ore would never be in the proper place to show these effects satisfactorily.

The ore itself will be a crystalline magnetite or hematite, probably very low in phosphorus, and possibly high in sulphur. It might also fairly be expected to be high in titanium, chromium, nickel, copper, or scarcer metals. If our field example shows high phosphorus the probabilities of its igneous origin are lessened; and if the phosphorus is present as separate crystalline grains of lime phosphate, the difficulties become very great.

Summarizing these points, it will be seen that the criteria developed are largely negative. Even when dealing with igneous activity of recent date, it will often be difficult to discriminate between magmatic segregations and contact deposits; and when dealing with old and highly metamorphosed rocks the uncertainties will be far greater. Under these circumstances it seems safest to assume that the burden of proof is always heavily against the direct igneous origin of any given ore-body.

Chief Possible Occurrences.—There are, of course, very wide differences of opinion among geologists as to what great iron-ore

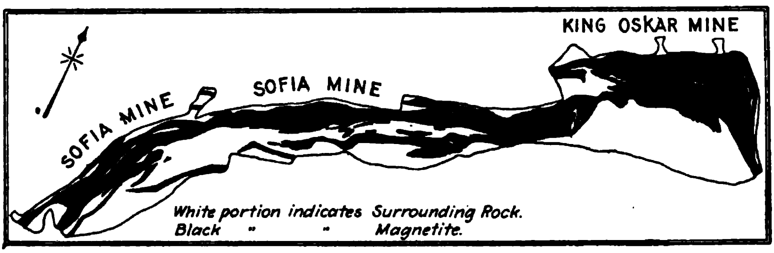


FIG. 20.—Scandinavian ore-bodies showing tabular or linear arrangement of magnetite bodies. (Stützer.)

deposits, if any, should be considered as of probable or certain magmatic origin. This condition prevents any very precise or definite statement as to the chief occurrences of possible or probable igneous ores. It may be said, however, that there are a number of instances in which there is either substantial agreement among most geologists, or firm conviction of the part of a few whose standing is sufficient to warrant consideration.

The principal instances falling in these classes are (1) the high titanium magnetites associated with basic rocks in many parts of the world; (2) most of the higher grade magnetites of Scandinavia; (3) many of the magnetites of the eastern United States and Canada.

It will be recognized immediately that the proof, with regard to the different instances above listed, is not of the same grade or character. Perhaps it would be fair to say that it is very convincing with regard to most of the titaniferous ores; that it is less certain with regard to the Scandinavian magnetites; and that it is quite weak indeed as far as the Adirondack and other non-titaniferous American magnetites are concerned.

THE TITANIFEROUS MAGNETITES.

Since the titaniferous iron ores form the only large class on which opinion as to their magmatic origin is substantially in accord, it will be well to discuss in some detail the facts as to their geologic associations, the form and relations of the ore-bodies, and the general character of the ores. There is the more reason for doing this in the present place because, as the titaniferous ores are not at present commercial raw materials, little attention will be given to them in the later chapters on the occurence of the iron ores of the world.

Associated Rocks.—With few exceptions, not sufficient to invalidate the general rule, the titaniferous iron ores are associated with very basic igneous rocks. Kemp states that normally these are of the general types of gabbros; and range through anorthosites, gabbros, norites, diabases and peridotites. The exceptional instances above noted are associated with somewhat more acid rocks—the nepheline syenites. The following analyses, quoted from Kemp, will serve to give some idea of the general chemical character of the enclosing rocks.

ANALYSES OF WALL-ROCKS, TITANIFEROUS ORES

	(1)	(2)		(1)	(2)
Ferric oxide	1.39	4.63	Lime	8.36	10.20
Ferrous oxide	10.45	12.99	Magnesia	7.10	5.34
Titanic oxide	1.20	5.26	Potash	0.81	0.95
Silica	47.88	44.77	Soda	2.75	2.47
Alumina	18.90	12.46			

[1] Split Rock mine, New York. W. H. Hillebrand, anal. 19th Ann. Rep U. S. G. S., pt. 3, page 402.

[2] Lincoln Pond, N. Y. G. Steiger, anal. Same, p 407.

Form and Relations of Ore-body.—The known deposits of titaniferous ores occur mostly in masses of irregular shape, enclosed entirely within bodies of gabbro. Occasionally the ore penetrates the igneous rock in sharply edged dikes, but normally the ore grades on every side gradually into the enclosing igneous rock.

Composition and Character of the Ores.—The titaniferous ores of magmatic origin are predominantly mixtures of magnetite and ilmenite, with of course more or less of gangue material. The latter, being simply portions of the associated igneous rock, consists of various minerals such as augite, the basic feldspars, etc. When free from gangue the ore is normally very low in phosphorus and usually low in sulphur; vanadium and chromium are commonly present in traces at least; manganese is low, and somewhat unexpectedly copper and nickel are rarely present. Taken as a whole the titaniferous ores are rich in iron, even allowing for the titanium present; and they are usually more massive and naturally concentrated than the non-titaniferous magnetites.

Bibliography of Titaniferous Ores.—The subject of the titaniferous ores is one of much interest from the purely geologic standpoint, and it seems probable that in the near future it may become of serious commercial importance. A large number of papers and reports refer to it, in one way or another, but no attempt has been made to prepare a complete bibliography. The few papers listed below are all important, and all very complete within their respective limits. They are, moreover, readily accessible to most engineers, and contain references to other literature which will facilitate further study of the subject.

Kemp, J. F. The titaniferous iron ores of the Adirondacks. 19th Ann. Rep. U. S. Geol Survey, pt. III, pp. 377–422. 1899.

Kemp, J. F. A brief review of the titaniferous magnetites School of Mines Quarterly, vol. XX, pp. 323–356; vol. XXI, pp. 56–65. 1899.

Newland, D. H. Geology o the Adirondack magnetic iron ores. Bulletin 119, New York State Museum. 1908

Singewald, J. T. The titaniferous iron ores in the United States. Bulletin 64, U. S. Bureau of Mines. 1913.

PART II.—THE VALUATION OF IRON ORE PROPERTIES

CHAPTER IX

THE BASAL FACTORS IN ORE VALUATION

Determining the value of a given amount of iron ore, whether that amount be a small mined tonnage ready for market or a large unmined reserve, is a matter which involves very complicated industrial and commercial relations. In the present volume all of Part II is devoted to various phases of this subject; and in order that the general bearing of this mass of details may be clearly understood, a brief introductory chapter is necessary to summarize the subject.

General Bases of Property Valuation.—In attempting to place a value upon a large iron-ore property, or group of properties, we have first of all to consider the reason for which the valuation is being made, and the use to which it will be put; for these factors will have an important influence on both the general methods and the details of the valuation. At first sight this statement may seem unsound, for it may be held that the value of a given piece of property is a fixed and definite matter, and that all logically correct methods should give the same results. Closer examination of the question, however, will prove that valuations are not of themselves definitely fixed, that they will vary greatly according to circumstances, and that this condition is not confined to the particular type of properties now under discussion, but is common to all the affairs of business life.

Whatever type of property we may consider, whether land, buildings, securities, or iron ores, there will inevitably be found to exist at least two separate and distinct methods of valuation, which may give more or less widely different results. Each of these methods is logically sound, each may be financially correct, and the choice between them will depend entirely upon the reason for which the valuation is being made. If it is to be used

as a basis for buying or selling the property at any particular time, we will be concerned only with the market or re-placement value of such a property. But if the property is to be put to a definite use by its present owners, and if by this use it will bring in larger profits than its present selling or re-placement price might indicate, the owners are fairly justified in taking this fact into account, and in assuming that *to them* the property has really this higher value due to expected profits. It is to be borne in mind, however, that such higher value should never be considered as being more than a matter of personal interest. The owner is entirely justified in relying upon it, for in the long run his earnings from it will be enough to cover the advance, but he would not be justified in attempting to borrow on the property at this higher value, or in expecting to realize that value at forced sale.

One fact remains to be noted, though to business men it will seem so obvious as to be hardly worth mention. Recent events have shown, however, that what may seem obvious to business men may be an impenetrable mystery to lawgivers, and for this reason it may be profitable not only to mention but to emphasize this very commonplace statement. *The value of property is not fixed or determined in any way by its original cost.* It is perfectly true that the cost of a property, plus carrying charges, represents the least price which the present owner can accept without losing money. But it neither guarantees that he can secure this price, nor makes it either reprehensible or foolish to ask a higher price, if the property has actually increased in value during the period of his ownership. Very few people, even in Congress, would question this statement as applied to the value of a farm owned by a constituent. When it comes, however, to the question of placing a valuation on a railroad, a mine, or a mill owned by a corporation, the matter for some reason appears to take on a different aspect. Of course in the case of public utilities there is some reason for this change in view, but this is not true in the case of manufacturing or mining properties, whether owned by corporations or by individuals.

Valuation of Ore Reserves.—Up to this point the matter of valuation has been discussed in an entirely general manner, and the principles which have been referred to can be applied in the valuation of any kind of property. The exact manner in which

they are applied, and the data which must be introduced in order to secure accurate results, will of course differ according to the type of property which is under consideration. At present we are concerned with the valuation of iron-ore properties, and with this in view it is possible to state certain features of the problem in detail, and to suggest fairly close limits for the various factors which are involved in the valuation of this type of property.

At the outset, one point must be firmly impressed. It is true that in placing a value on an iron-ore property we may often properly consider it as merely the valuation of real estate, and apply some of the principles on which ordinary land is commonly valued. But it is real estate of a very special kind, and in most cases it owes all its value to the rate at which it will be used and exhausted. At times, it is true, there will remain a certain realty value for the land after its iron ore has been exhausted; and in some instances the land can be used for other purposes before iron-ore mining has been commenced. But in by far the majority of cases the iron property is a dead burden until ore production has started, and is absolutely valueless after it has ceased. Under these circumstances there is usually little need to consider such questions as surface rentals or surface land values; and the unit of valuation must be the ton of ore and not the acre of land. And, as will be seen later, time is as important a factor as tonnage in determining the total present value of the property.

In an earlier section of this chapter it was pointed out that the reasons for the valuation, and the intentions of the owner, would each have an effect on the methods to be followed and on the results that would be obtained. It seems clear, for example, that if the purpose of the valuation is the issue of bonds against the property, a proper regard for the security of these bonds will involve valuation on a strict market basis, as nearly as such basis can be determined. On the other hand it seems equally clear that if the owner has arranged to have the ore mined on a royalty basis, the rate of extraction, the rate of royalty, and other features of the agreement must be taken into consideration in arriving at a proper valuation. To me it seems that in some cases we may go even further than this, and equitably capitalize a portion of the smelting profits when the owner of the ore land expects to use the ore in his own furnaces.

There are thus three different bases on which the valuation of

an iron ore property may be placed. For convenience these may be briefly described, in an order different from that in which they are noted above, as:

1. *Capitalization of Smelting Profits.* 2. *Capitalization of Royalties or Mining Profits.* 3. *Market or Replacement Valuation.*

Each of these is logically sound, under certain conditions, though each method will give a different final result. It is therefore advisable to consider them separately, to state the conditions under which the different methods are available, and to give some idea of the different results which will be obtained by their use.

Capitalization of Smelting Profits.—The method of valuation to be considered under this head will undoubtedly be looked upon as highly unsound, when applied to iron mining, though it will be the merest commonplace to anyone engaged in mining copper, lead, silver, or gold ores. We have, in other words, to deal with a method of valuation which is logically sound and defensible under certain conditions; which is universally adopted in valuing all mining property except iron mines; but which has never to my knowledge, been suggested for use in iron mining. It is not here recommended for use under ordinary conditions, but is discussed simply in order to point out that under certain given conditions it could be adopted and justified.

In speaking, for example, of the valuation of a developed gold mine, the final statement will ordinarily take the form of saying that the property contains a certain number of tons of ore, with an average net value of so many dollars per ton. The total value of the property will then be placed at the product of these two figures, with some discount for the years required to work out the mine. The same form of statement would be used in discussing a copper mine, though in this case owing to the variations in the price of copper, the statement would have to be qualified by saying that it was based on the assumption that during the life of the mine metallic copper averaged so many cents per pound. In neither case would anyone connected with the mining industry see anything remarkable in the form of statement, or in the general method which had been employed. But if we should value an iron mine on precisely the same basis, the results would be very remarkable, and everyone would criticise the methods adopted. Yet there is no good reason for making any difference

between the two cases, except that trade customs have been different.

In mining any ore except iron, we are accustomed to credit the ore with the total *net* profit of all the series of operations from mine to finished and marketed metal. In other words, the net value of a ton of gold or copper ore is always taken as meaning the profits per ton which can be credited to the mine after all the expenses and losses of mining, smelting, transportation and refining have been met and allowed for.

In dealing with iron ore, however, the practice has been very different. Here it has been the custom to credit the bulk of the profit of the series of operations, not to the mine, but to the blast furnaces or steel-mill. The results have been, in some sense, unfortunate; for this method of crediting most of the profits to a late stage in the process has encouraged the public idea that the profits of iron and steel *manufacture* are excessive. Mining has always been looked upon as a commercially hazardous occupation, whose risks must be compensated for by the possibility of larger profits than can fairly be asked or expected from ordinary business. There has never been serious criticism of copper mines because of their occasional large earnings, and there is no good reason why iron mining should be placed upon any other level in the public estimation.

The method of valuation which has been here suggested is clearly justifiable, but as it has not been adopted in the past there is no need to discuss it in more detail. The methods which remain to be considered are both justifiable and in regular use.

Market Valuations.—Another method of valuation, which theoretically should give about the same final results as the one which will be next discussed, is to work out the problem from the current prices of similar ore lands in the same district. A modification of this method, which is here put in use for the first time, is to work it out from the market value of securities issued against ore properties. Neither of these methods can be applied automatically or unintelligently, for it is necessary that the property whose value is to be determined shall be closely comparable in every way with the properties of known value used for comparison.

The market value of an ore property will depend upon a number of factors. The one which comes first to mind, and is most

commonly discussed in this connection—*i.e.*, the grade of the ore itself—is after all of quite subordinate importance except in comparing two closely similar properties in the same district. The most important matter is the relation between supply and demand in the particular district where the property is located, and this fact is constantly forgotten in current discussions of the subject. As an instance in point, we may take the South, where ore lands are still sold at a very low price per ton. This condition is *not* due primarily to the low grade of Southern ores, but to the fact that the Southern States contain some 3,000,000,000 tons or more of iron ore; and that this huge reserve is being used at the rate of only some 5,000,000 or 6,000,000 tons a year. In the Lake region, a total reserve of slightly smaller size is being drawn on at the rate of almost 50,000,000 tons a year. It is obvious that the Lake supply, in relation to the demand, is more than ten times as scarce as the Southern supply. Even if Lake ores were of poorer grade than the average Southern ore, they would still be worth far more money per ton because of this relation.

As a matter of fact, we do find that this relation holds when we come to compare the market values of Lake and Southern ore properties. In the South it is still possible to buy ores at the rate of one cent per ton or less; and it is rarely necessary to go over two or three cents a ton except for small, easily developed and exceptionally well-located holdings. Compared with this, we find that in the Lake regions the Minnesota and Michigan ore lands are actually taxed on a basis which implies that they are worth from forty to eighty cents a ton.

A curious check upon the substantial accuracy of the above figures is afforded by using the method which the writer recently developed for a special purpose. In this method security prices are used after making allowances for the value of the other properties covered by the securities, for determining the values placed by the Stock Exchange on raw materials. The method will not be widely applicable, for it requires some detailed knowledge of the companies whose securities are compared, but when it can be used at all its results are peculiarly valuable. It will not be necessary to discuss the method or results here in detail, but one set of comparisons will be of present interest. It covers the results secured by comparing a company having its ores in the

Lake region, with another company based on Alabama ores. The valuations per ton placed on the ores by the New York Stock Exchange, at two important periods, were as shown in the tabulation below:

	High of 1906	Panic of 1907	Average
Lake ores	53.10 cts.	20.25 cts.	36.67 cts.
Alabama ores	2.66 cts.	1.20 cts.	1.83 cts.

Of course too much stress should not be laid upon this method of determining values, for the Stock Exchange is subject to errors of judgment. But it is, after all, the broadest market we have for large properties, and the value which it places on them must be taken into account.

Capitalization of Royalties or Mining Profits.—In by far the majority of cases, particularly where an individual ore-property of moderate size is under consideration, the method of valuation adopted will involve capitalizing the expected royalties or the expected mining profits. When this method of valuation is adopted, the total present value of the property will depend upon three factors:

a. Total tonnage of merchantable ore on property.

b. Royalty or net profit per ton of ore.

c. Rate at which the ore will be extracted.

Of the three factors named, the total tonnage is determined as an engineering and geologic problem, the methods for such determination being discussed in detail in Chapter X. As to the other two factors, they may either be definitely known (as when a specific lease is under consideration or in force), or it may be necessary to estimate them from past experience. In the last case we have to deal respectively with such factors as probable mining costs, grade and composition of ore, concentrating methods and costs, current selling prices of ores in competitive markets, probable demand for ore, and current interest rates.

To summarize the matter, it may be recalled that three factors have been named as affecting ore reserve valuations. These three factors are (1) tonnage on property, (2) value per ton of ore, and (3) rate of extraction. To determine the present value of an ore property three operations are therefore necessary. These operations, with the chapters under which their details are discussed in the present volume, are as follows:

A. Determining the *total tonnage* on the property.
  Chapter x Prospecting and Tonnage Determinations.
B. Determining the probable *profits per ton*.
  Chapter xi Mining Costs.
  Chapter xii Furnace and Mill Requirements.
  Chapter xiii Composition and Concentration.
  Chapter xiv Prices, Profits and Markets.
C. Determining the *present value*.
  Chapter xv Time as a Factor in Valuation.

References on Reserve Valuation.—Incidental references to the subjects which have been discussed in this chapter will be found scattered through mining literature, and some of these minor contributions to the problem offer valuable material for study. The books listed below, however, are devoted chiefly or entirely to this phase of mining.

Finlay, J. R. The Cost of Mining. 8vo, 415 pages. McGraw-Hill Book Co., New York, 1909.

Hoover, H. C. Principles of Mining. 8vo, 199 pages. McGraw-Hill Book Co., New York, 1909.

Lawn, J. G. Mine Accounts and Mining Book-keeping. 8vo, 147 pages Charles Griffin & Co., London, 1907 (5th edition).

Of the three volumes named above, Finlay's book is of greatest value in the present connection, devoting most space to the principles which underlie the valuation of ore reserves. Hoover, though also discussing this phase of the subject, is chiefly interested in the actual methods of determining the reserves. Lawn's book, as indicated by its title, is chiefly devoted to accounting method, but contains some valuable discussion of the principles and methods of amortization.

CHAPTER X

PROSPECTING AND TONNAGE DETERMINATIONS

In the previous chapter it was pointed out that the tonnage of ore contained in an iron-ore deposit is one of the three basal factors on which depends the value of that deposit. The other two factors will be taken up later, but the present chapter will be devoted to consideration of the methods of determining ore tonnage.

The ore deposit or district which is to be examined may be an entirely new and undeveloped field, or it may be a portion of a worked territory; and these conditions will naturally influence the character of the work which has to be done in the course of the examination. Even in unworked areas it is usually the case that there has been more or less desultory prospecting or development work carried out by the discoverers of the ore; but in order to secure sufficient data for tonnage estimates it will almost inevitably be necessary to do much more of such work. The extent of this later prospecting will depend very largely upon the causes which have led to the examination.

Reasons for Valuation.—The bulk of the work done in the way of valuing iron-ore deposits or reserves will fall under one or the other of the following cases:

1. An existing furnace company wishes to secure an additional ore supply. In this case there will be existing data on freight rates, coke costs, etc., so that in order to determine the value of the ore to the company only its composition, tonnage and mining possibilities need be considered.

2. Several existing companies wish to have their properties appraised, for the purpose of consolidation. In this case the values may be entirely arbitrary without injustice, so long as they are directly comparable.

3. An ore property is to be examined for the purpose of organizing a separate ore-mining company. Except in the Lake Superior district, where certain standards of value are well

understood, this is the most difficult case of all, for it involves the study of all competitive ores as well as of possible markets.

4. An ore deposit is to be examined for the purpose of organizing a new furnace company. In this case competitive ores require less attention; but this is counter-balanced by the heavier investment which will be based on the examination.

THE STUDY OF ORIGIN AND RELATIONS

Geologic Examination.—It seems hardly necessary to say that until the engineer charged with the examination of an iron-ore property has arrived at reasonably satisfactory conclusions regarding the origin and geological relations of the ore deposit, he will be entirely unable to give an opinion of any value regarding the probable continuity of the ore-bodies either laterally or in depth, the tonnage available at working depths, or the value of the property. Such opinions can only be arrived at by making assumptions on certain points, and all of the assumed factors are matters to be determined largely by geological reasoning and not by purely engineering methods. This implies simply that in order to satisfactorily handle the problems which will present themselves during such an examination the engineer must possess a fair knowledge of applied geology, and that he shall be capable of making use of this knowledge in the field.

Before commencing the actual prospecting work it will therefore be advisable to devote some time to a study of the geology of the area, mapping roughly the different formations, determining if possible the underground structure of the rocks, and studying the geologic relations of the ores. The time to be spent on such a study will depend on the area to be covered, the total time available, the importance of the property, and the character of the ore deposits. In dealing, for example, with well-known sedimentary deposits such as the Clinton hematites of the southern United States, which occupy a very definite geologic position, little time need be spent except in the determination of the existence and location of folds and faults in the strata. If, on the other hand, the problem concerns a magnetite or brown-ore body of unknown origin and relations, time spent on a study of all important geologic factors will never be wasted.

It must be borne in mind that it is rarely necessary for the

engineer to commence this local geological study in entire ignorance of what he may expect to find. Something is usually on record concerning the district, if one knows where to look for it. In states and countries that have arrived at a fairly high level of civilization the engineer will usually find a more or less valuable series of reports by the State or National Geological Survey, and inquiry will commonly develop the fact that there is considerably more unpublished material on file at their offices. In regard to less-known districts books of travel, consular reports and scientific journals will frequently be found to contain information of value.

Probabilities as to Origin.—Of course each particular ore deposit or group of deposits will require individual study before anything definite can be said concerning its origin. But a good deal of time can be saved in these studies if it is realized at the outset that there are certain probabilities which are worth considering. For the facts on which these probabilities are based, reference must be made to the details given in the preceding chapters (Chapters II to VIII) dealing with the origin of iron-ore deposits. In the present place it is only necessary to state briefly the conclusions which appear to be justified in the light of our present knowledge. It will be seen that these conclusions are of very direct and practical service during the preliminary examination and the prospecting of a new ore deposit.

Based on the kind of iron ore which the deposit shows at the surface, the probabilities as to the origin of the deposit may be stated as follows, the likeliest mode of origin being in each case noted first:

Carbonate ore:
1. Sedimentary bed.
2. Replacement of limestone.

Brown ore:
1. Residual ore.
2. Gossan or surface alteration of contact deposit.
3. Normal replacement of limestone or, less commonly, sandstone.
4. Sedimentary bed.

Hematite:
1. Sedimentary bed; if oölitic or granular texture.
2. Contact deposit.
3. Replacement; usually of limestone.
4. Secondary concentration.

Magnetite:
1. Contact replacement.
2. Metamorphosed sediment or replacement.
3. Magmatic segregation; if in basic igneous rocks.

Of course the preceding summary does not cover all the possible ways in which any of these ores may originate. But it does include the types in which they are most likely to be found; and it lists them, on the whole, in about the order of their probability.

Application of Geologic Studies.—Assuming that it has been possible for the engineer to come to some tentative conclusion as to the probable manner in which the ore deposit originated, it remains to put this conclusion to service in laying out the prospecting work. Much depends of course upon local conditions, so that no hard-and-fast rules can be laid down for translating the results of the geologic study into practice. But it is possible to point out certain facts of very general applicability.

The principal relations existing between mode or origin and character of prospecting work will affect the extent of work required, the direction in which work is most desirable, and the reliance to be placed on individual analyses or excavations. Each kind of deposit differs in these regards, so that the matter can best be placed in useful form if arranged according to general type of deposit.

Sedimentary Deposits.—Occurring as distinct beds, usually extensive in area. Variations in composition greater across the bedding than along it. Occurrence of ore has no relation to present land surface; and only reason for deep drilling is to check up estimates as to depth, etc. Prospecting may be relatively slight and still give good basis for tonnage estimates. More care required in getting good average samples to show actual shipping grade. If samples run low in phosphorus, further examination is desirable, as this is unusual in sedimentary deposits. If extensive operations are planned, faults must be looked for carefully.

Normal Replacements.—Determine what kind of rock has been replaced, and get some idea of its areal distribution and geologic structure. In steep-dipping beds deposit will usually replace a special bed and form a tabular mass; in massive or flat-lying rocks it will be irregular. In either case widest ore-body and

best ore is likely to occur at or near the present ground surface; and ore deposit will terminate at some moderate depth. Latter point may be determined by drilling or cross-cutting if topography is favorable. Presence of iron carbonate usually indicates that bottom or side of deposit is being approached.

Secondary Concentrations.—Locally very important, but not of widespread occurrence. In a new district they will be treated like normal replacements. Chief differences are that ore is not necessarily best and thickest at present surface; and that separate deposits may be struck in depth.

Contact Deposits.—No relation to present surface; ore body usually borders contact of igneous rock; occasionally diverges from this contact to follow some particular bed or zone in the other rocks. Other dimensions very irregular and impossible to estimate in advance; close prospecting therefore required in every direction. Particular attention must be paid to sulphur in samples; danger that it will increase with depth.

Residual Deposits.—Ore deposition related to existing or recent topography; deposit will therefore thin and possibly lower in grade with depth when standing in vertical or inclined position. When present ore-body occurs as a more or less horizontal mantle, its area may not decrease in depth, but the total depth to which it extends is apt to be small—say 50 feet or less. The grade of a mantling ore-body may change in depth, and sometimes the best ore is found near the base of the deposit. In any case deposit will terminate in depth by running into solid rock or pyrite. This class includes some easily prospected deposits, but in general the residual ores will cost more for prospecting, per ton of ore developed, than any other type.

PROSPECTING METHODS AND COSTS

Available Methods of Exploration.—The five methods grouped below cover all the methods of exploration which are generally useful. Of the five, three are drilling methods; while two depend upon actual excavation.

1. *Core drilling*, in which a rotating hollow bit cuts a solid core; the sample being brought up in its original condition.
2. *Churn drilling*, in which tools suspended by rods and cable make their progress by impact; the sample coming up as slime or mud.

3. *Auger drilling,* in which an auger, screwed to the end of a series of lengths of bar or pipe, is rotated by hand; the sample being caught in the thread of the auger.
4. *Pits and shafts,* for vertical exploration.
5. *Trenches and drifts,* for horizontal exploration.

Choice of Methods.—The adoption of one or the other of these methods may be dictated by the necessities of the individual case. For example, it would be ridiculous to go to the expense of diamond drilling in examining a small or otherwise unimportant ore-body; while absence of good water supply would be an argument against either diamond or churn drilling. Aside from these local or individual reasons, however, there are certain broad principles which will usually lead to a choice among the various methods. The facts in the case are stated on pages following, and their effect on choice of methods may be summarized as follows:

For cross-cutting inclined beds:
- Trenches or drifts; usually both.

For proving either bedded or irregular ore-bodies in depth:
- In hard rock:
  - Core drill usually; occasionally churn drill.
- In soft rock, clay, etc.:
  - Pits for shallow work—say up to 20 feet—or for deeper work if timbered.
  - Auger drilling for shallow to medium depths (0–80 feet) in clays, soil, etc.
  - Churn drilling for depths between 50 and 1000 feet.

For determining lateral extent of irregular shallow deposits:
- Pits or trenches almost always most economical.
- Auger or other drilling when overburden exceeds 25 feet or so.

Core Drilling.—In speaking of core drilling, it may be assumed that diamond drilling is meant, for other methods of core drilling are in general less efficient in dealing with hard materials. The chief advantages of core drills are, of course, that they furnish a good sample of the ore; and that they determine its thickness and depth very precisely. As against this, they are expensive as compared with other methods; they fail in creviced or loose rock; and they lose their advantage sharply as the depth of soil and other overburden increases. For two particular purposes they are particularly adapted; to determine the shape and extent of pockety or irregular ore-bodies enclosed in hard rock, and to determine the thickness, grade and depth of bedded or lenticular ore-bodies in depth. Finally, it is to be noted that the use of

core drills is of more service in the close final work than in the earlier stages of prospecting an unknown property; and that the records of the work should be kept with a care proportionate to their precision and their cost.

Total costs may vary from $1.50 per foot to $3.00 or more, for very deep holes.

Churn Drilling.—The use of the regular well-drilling rig has spread from oil and gas exploration to work in iron fields, to which it is not by any means so well adapted. It is possible to reach great depths with the churn drill, but the samples are always poor and the analytical results usually doubtful. When the ore occurs as a definite bed, enclosed in rocks of widely different character, the results by this method are good enough, and in this case its lower cost gives it the preference over core-drill work. Hard rock or boulders increase costs heavily. On the average, costs may vary from somewhat less than $1.00 to $1.50 per foot or over. For very shallow depths, say 100 feet or less, the time lost in moving the rig is a heavy item, though for these depths the cost of the actual drilling is very low.

Auger Drilling.—The earth-auger, originally used in exploring clay deposits, has proven to have a certain field of utility in iron-ore exploration. Catlett and others have used it in prospecting brown-ore deposits, and have found that within a limited field it has the advantages of cheapness and handiness. The entire rig can be made up at any blacksmith shop in a few hours if necessary, and as a matter of fact all the parts required are ordinarily carried in the stores of every mining camp.

The limitations of this method are marked. It can not penetrate hard material, being unavailable against hard rock or even boulders. On the other hand, in soil or clay it makes very rapid progress. The depth is limited by the difficulty of pulling the string of rods, so that 30 feet is the usual maximum unless tackle be rigged. These conditions really limit the auger to use in shallow deposits of brown ore.

As the auger rig will usually have to be improvised by the engineer on the ground, the following data quoted from a paper by Catlett in the Transactions of the American Institute of Mining Engineers may prove of service:

The outfit required for projecting work consists of:

1. "An auger-bit of steel or Swede iron, with a steel point, twisted

into a spiral, with an ultimate diameter of 2 inches, and an ultimate thickness of blade of not less than $\frac{1}{4}$ inch. The point is found more effective when split. The length of the auger proper was gradually increased until about 13 inches was reached as the apparent maximum which could be used effectively. The 13-inch auger contains four turns. This was welded to the end of 18 inches of 1-inch wrought-iron pipe, on which screws were cut for connection.

2. "One foot of $1\frac{3}{8}$-inch octagonal steel, with a 2-inch cutting face, which is likewise welded on to 18 inches of pipe, cut for connections.

3. "Ten feet of $1\frac{1}{4}$-inch iron rod, threaded at either end for connection with 1-inch pipe. When connected with one of the drill-bits this becomes a jumper for starting holes through hard material. It is also used when desired to give additional weight to the drill in going through rock below the surface.

4. "Sections of 1-inch pipe and connections.

5. "An iron handle, with a total length of 2 feet, arranged with a central eye for sliding up and down the pipe and with a set-screw for fastening it at any point.

6. "A sand-pump, consisting of 1 or 2 feet of 1-inch pipe, with a simple leather valve and a cord for raising and lowering it.

7. "Two pairs of pipe-tongs or two monkey-wrenches, with attachments for turning them into pipe-tongs.

8. "Sundries: 25 feet of tape, oil-can, flat file, cheap spring-balance, water-bucket, etc.

"The auger is used by two men, who, standing on opposite sides, turn it by means of the handle. The handle is also useful in giving a good purchase for starting the auger from the bottom of the hole, in opposition to the air-pressure, which is considerable. Enough water is continually used to just soften the material. Usually the auger brings up a small portion, which is dry and unaffected. Every few minutes, as the auger becomes full, it is lifted out, scraped off and replaced. The handle is moved up and tightened by means of the set-screw as the auger goes down. At every slight change of the material the depth and the character of the material are recorded.

"When hard material is encountered the auger-bit is screwed off and the drill-bit screwed on, thus forming a churn-drill, which may be used for passing through the hard material, the auger being replaced when softer material is reached. The churn-drill is used by lifting it and letting it fall, turning it slightly each time. Its weight makes it cut quite rapidly. When the drill is used the muck is either worked stiff enough to admit of its being withdrawn with the auger, or it is extracted by means of the sand-pump or a hickory swab. In either case the material is washed and a sample is obtained of the stratum through which the drill is cutting.

"Of course, the best work with such tools is done on soft material, but it is entirely practicable to go through hard material (a few feet of quartzite or flint, and many feet of ore being often encountered in a single hole), and the ability of this simple contrivance to go through interbedded layers of hard and soft substances makes it very efficient.

"The cost per foot increases considerably with depths exceeding 50 feet, but at the greatest depth I attained (some 80 feet) I did not reach either its capacity or the limit of its economical use as compared with other methods.

"Up to 25 feet, two men can operate it; from 25 feet to 35 feet, three men are necessary; from that to 50 feet, a rough frame, 15 feet to 20 feet high (costing something over $1.00), for the third man to stand on, is required. The frame can be moved from point to point. Above 50 feet it is generally necessary to take off one or two of the top-joints each time the auger or drill is lifted."

Pits and Shafts.—For an ore deposit which commences at or near the ground surface, test pits will probably be the first method thought of. Under such conditions they give the maximum of information, and are less expensive per foot of depth than either churn or core drills. Their possible depth is limited, however, for in ordinary materials it is rarely safe to put them down more than 30 feet without some sort of light timbering. This, and the hoisting necessities, make deep test pits rather more expensive than might be expected. Up to 50 feet they may justify this expense. For greater depths, unless the prospect shaft finally develops into a regular shaft, it will probably be found cheaper to take up one of the drilling methods. Test pits may range in cost from thirty to fifty cents per foot for untimbered holes ranging from 10 to 30 feet deep.

Trenches and Drifts.—For cross-cutting an inclined ore-body, trenches on the surface and drifts below the outcrop give better results than test pits or drilling. When the ore-body is struck, headings may be turned off along it to develop its length and continuity. The cost of such work will depend on the hardness of the material passed through, and on the amounts of timbering required. For short drifts, run for information only, timbering can be limited to actual immediate necessities; but if the drifts are expected to stay open for a year or more, they must be put in better shape. In this connection it is well to recollect that safety must be given consideration in prospecting work as well as in actual mining. The scattered nature of the workings, the dis-

tance from help and the relative lack of supervision all combine to make greater care necessary during the prospecting than at later stages of the mining work.

ORE DENSITY; SPACE AND TONNAGE CONVERSIONS

Throughout all of the preceding portion of this chapter, we have been concerned chiefly with the manner in which the size of the ore deposit is to be determined. Whatever the methods of prospecting adopted, the final results of it will be expressed in terms of space—we will have determined that there are a certain number of cubic feet of ore available in the given deposit. But, since ore is actually sold by the ton and not by the cubic foot, it is obvious that it will be necessary to convert these space measurements into tonnage figures before we have really completed the work of quantity determination.

Theoretical or Maximum Density.—It will be convenient to determine first the maximum density which a theoretically pure ore of any type could possibly attain, since this will set a limit in one direction for the variations observed in actual practice.

If we were dealing with absolutely pure ores, at their maximum density, the four important iron minerals would give the results shown in the following table. The specific gravities for hematite and siderite are quoted from F. W. Clarke; the brown-ore density has been calculated from the value for hematite, on the theory that the common type of brown ore may carry 10 percent of combined water. Using these specific gravity data as bases, the weight per cubic foot and the number of cubic feet required to make up a long ton have also been calculated for the table.

DENSITY OF PURE IRON MINERALS

Ore	Spec. gravity	Weight per cubic foot	Cubic feet per long ton
Magnetite	5.2	324.5 lbs.	6.9 cu. ft.
Hematite	5.2	324.5 lbs.	6.9 cu. ft.
Brown ore	4.8	299.5 lbs.	7.5 cu. ft.
Siderite	3.9	243.4 lbs.	9.2 cu. ft.

Factors Decreasing Density.—The data given in the preceding table relate to ores which are (a) theoretically pure iron minerals, and (b) free from pore space. But ores, as actually found and mined, are never absolutely pure, and never quite free from pores or cavities of varying size. Both of these factors operate to

reduce the actual density of ores below the theoretical maxima noted in the above table.

In most cases, the effect of the rock impurities is by far the more important of the two causes of decreased density; but when dealing with the brown ores or with some of the softer hematites the effect of porosity is very marked.

Some idea of the effect of impurities in reducing ore density can be gained from the following summary, which gives the specific gravity of the rocks and other materials likely to be associated with the ores.

DENSITY OF GANGUE MATERIALS

Rock or mineral	Specific gravity
Quartz	2.5 to 2.8
Apatite	3.18 to 3.25
Calcite	2.5 to 2.8
Clays	1.9 average
Shales	2.4 average
Slates	2.7 to 2.9
Limestones	2.3 to 2.9
Sandstones	2.0 to 2.7
Granites, gneisses	2.66 average
Traps	2.7 to 3.1

It will be seen that, excepting titaniferous minerals and pyrite, all of the common impurities or associaties of iron ores are far lower in specific gravity than any of the iron minerals themselves.

Density of Actual Ores.—The following data on actual ore densities in various ore districts, covering different types and kinds of ore, will be of service in checking up tonnage estimates in materials of similar type.

Taking up first the Lake Superior ores, the figures which follow are summarized from data presented by Van Hise and Leith on various pages of Monograph LII, United States Geological Survey.

CUBIC FEET PER TON

Range	
Vermillion	Usual estimates 9 to 10 cubic feet per ton. Actual calculations show 8.75 feet for Soudan ore and 9.5 feet for Ely ore.
Michipicoten	Range very wide; average 13.5 feet per ton.
Mesabi	Range very wide; from 9 cubic feet per ton for densest ores, to 17 or 18 feet for hydrated ores; average for range approximately 12 cubic feet per ton.

CUBIC FEET PER TON

Range	
Cuyuna........	Hard ores average 10 cubic feet per ton; soft ores average 11.5 cubic feet; average for a large deposit consisting of both types might be 11 cubic feet per ton.
Gogebic.......	Range from 7.5 cubic feet for best hard ore, to 14 cubic feet in soft yellow ores. Average for range shipments about 10.75 cubic feet.
Marquette.....	Range from 7 cubic feet for best hard hematite and magnetite, down to 14.5 feet for hydrated ores.
Florence.......	Range from 8 to 15 cubic feet per ton, with average of about 11 cubic feet.
Menominee....	Range very wide; the bulk of the ores, however, will fall between 9 and 14 cubic feet per ton.

The red hematites of the Wabana field of Newfoundland range from 48 to 56 percent metallic iron, in the different beds, and their porosity varies somewhat. The two factors give a moderate range in density for the ores. Samples collected by E. E. Ellis, and determined at the Ensley laboratory, gave the following results for typical Wabana ores from the three workable beds:

Ore bed	Specific gravity
Upper seam	3.99
Scotia seam	3.95
Dominion seam	4.12
Average	4.02

This corresponds very closely to 9 cubic feet per ton. It may be of interest to note that the highest grade ore gave the lowest specific gravity, owing to its greater porosity.

The red Clinton hematites of the southern and eastern United States vary somewhat in density according to their iron grade, but far more widely according to whether they are soft (leached) or hard (unleached) ores. There is little interest left concerning soft ores, for they have been worked out almost everywhere. The hard or unleached ores are fairly dense materials, and show less variation in gravity than might be expected. Seven samples from the Birmingham district, ranging from 35.19 to 38.05 percent metallic iron, gave specific gravities ranging from 3.42 to 3.56. For all practical purposes it is safe to assume, as was done in the calculation of the Birmingham district ore reserves, that the hard red ores will run almost exactly 10 cubic feet to the ton. The soft ores show gravities from 3.5 to 4.2 in powdered form, but their porosity lessens their real density in the ground, so that

it is not safe to count on their yielding much more than the hard ores per cubic foot.

Massive bedded carbonates may run as high as 10 to 12 cubic feet to the ton as they occur in the ground. The nodular carbonates, with considerable waste material, are of course much less dense in a natural condition; and may range as low as 15 feet per ton.

Brown ores show the greatest variation in density. Pockets of high-grade ore may yield at the rate of 9 cubic feet per ton, but this is an exceptional condition. The brown ores of the Oriskany or Clifton Forge region of Virginia, which are perhaps the most solid of their type, yield at the rate of about 22 cubic feet per ton of washed ore. In southwestern Virginia and in north Georgia, where the washing ratio is higher, it may be necessary to allow 25 to 50 cubic feet to the ton of ore.

Magnetites of the Adirondack and other regions vary chiefly according to iron content, since none of them show much porosity. High-grade ores such as some portions of the Mineville deposits yielded, show 7 or 8 cubic feet to the ton. From this we can grade down, according to iron percentage, to 20 or 25 cubic feet per ton of concentrates, where a 25 to 30 percent ore is under examination.

CHAPTER XI

MINING CONDITIONS AND COSTS

However the ore deposit may have originated, and whatever the tonnage of ore it may contain, its proper development and utilization will involve a number of different operations before the ore is converted into merchantable metal. Summarized briefly, these will include mining the ore, in many cases concentrating part or all of the ore mined, transporting the ore to a furnace, smelting it into pig iron, and probably carrying the process further to steel conversion and the manufacture of finished products.

Any one of these operations would, if treated in technical detail, require a volume for its adequate presentation. But in the present place there is no necessity for discussing technical details or methods, except in so far as they influence the industrial value or competitive importance of ore deposits.

Keeping in mind this limitation in the scope of treatment, the present chapter will include some discussion of mining costs in various districts, for which ample details have fortunately become available recently. In later chapters the influence of furnace and mill requirements on ore values will be taken up, followed by discussion of natural ore grades and concentration possibilities.

General Mining Methods.—Probably nine mines out of ten are, at the very commencement of operations, worked as open cuts for a time. Ordinarily this lasts until the stripping becomes a serious problem, and then the question arises as to permanent methods. Under certain conditions there is, of course, little room for choice in this matter. A thin vertical or steeply inclined ore-body, extending downward to great depths, will necessarily be worked by means of a shaft or slope. An approximately horizontal ore-body, extending to the surface at many points, will almost necessarily be worked as an open cut. These two cases, whose method of treatment is obvious enough on merely stating the facts, include many of the iron-ore deposits commonly encountered. The eastern magnetites, for example, ordinarily

occur as more or less steeply inclined lenses; the Clinton red ores occur normally as inclined beds; and in each of these cases shafts or slopes are the only feasible methods of working. Most of our brown ores, on the other hand, occur as deposits reaching the ground surface at many points, and not extending downward to any great depth. In this case an open cut is the only thing to be considered.

But there are cases, and important cases, where there is distinct room for choice between the two methods of operation. The bulk of the Mesaba deposits, for example, would fall in this doubtful group; many of the Oriskany and other brown ores are equally open to discussion; and occasionally hematites and magnetites of other regions occur in deposits whose proper method of working may not be absolutely fixed by natural conditions.

The following comparison of costs as between the open-pit and the underground mines on the Mesabi range is quoted in slightly rearranged form, from the report of the Commissioner of Corporations on the Steel Industry, pt. 3, p. 43. It is based on a very large proportion of the total operations on that range during the years 1902 to 1906 inclusive.

	Open-pit mines	Milling and underground mines
Tonnage covered	28,984,383	35,500,173
Costs per ton		
Labor	$0.10	$0.40
Supplies	0.04	0.16
Repairs	0.01	0.01
General expense	0.01	0.02
Stripping	0.06	0.04
Actual mining costs	0.22	0.63
Depreciation	0.06	0.09
Royalties	0.24	0.27
Total cost per ton	$0.52	$0.99

A word of warning may not come amiss when such figures as these are under consideration. In considering the relative advantages of surface and underground mining, it must be borne in mind that the Mesabi offered exceptional conditions in favor of steam-shovel work. The individual deposits are large, continuous, and when once stripped the openings are practically free from waste matter. This brings down costs per ton of ore to a mini-

mum which is not likely to be approached in ordinary ore fields. In most parts of the world there will be sufficient irregularity in the ore deposit to increase actual operating costs very heavily, and there will be a large amount of dead work and exploratory work to be done which will add to total costs.

Cost of Mining Lake Ores.—When Finlay, in 1909, prepared his valuable monograph on "The Cost of Mining," he notes that he could find no general data on the cost of mining iron ores in the Lake Superior district. Data concerning the costs at individual mines were available, it is true, but none of these covered sufficient tonnage and sufficient variety in operating conditions to make them serviceable as bases for drawing conclusions regarding the average cost of the entire Lake Superior output, or of any considerable proportion of it.

In this respect, conditions have changed radically since 1909, owing to the extensive and unsolicited publicity which different branches of the iron business have received from various departments of both the Federal and the State governments. To one who has not kept close track of this line of activity, it is difficult to realize how far it has extended. The matter may fairly be summarized by saying that during the past three years investigations of more or less moment to the iron industry have been carried out by the House of Representatives, the Department of Justice, the Bureau of Corporations, the United States Geological Survey, and the Michigan and Minnesota Tax Commissions. Many of the results of these investigations have been placed before the public for its instruction or amusement. An estimate which I made recently places the total amount of reports and other publications issued by the above agencies, and dealing with the iron business since 1909, as being in excess of twenty thousand printed pages. For convenience we may say that over ten million words of printed information, advice or warning have been showered on this industry during the past three years.

Of course the bulk of this enormous tonnage is of no interest to the engineer, or indeed to anyone else dealing with the realities of life. But, on the other hand, it is very difficult for any set of men, the *Congressional Record* to the contrary notwithstanding, to utter ten million words on one subject without including any facts whatever. And so, on carefully examining this large mass of available published material, we are rewarded by coming at inter-

TABLE 1.—COST PER TON OF LAKE SUPERIOR ORES, 1902–1906

	Marquette	Menominee	Gogebic	Vermillion,	Old ranges, average	Mesabi	All ranges, average
Tonnage covered	12,616,253	11,358,357	11,548,988	6,260,574	41,784,172	64,484,556	106,268,728
Labor	$0.79	$0.79	$0.78	$0.50	$0.74	$0.26	$0.45
Supplies	0.29	0.32	0.27	0.23	0.28	0.10	0.17
Repairs	0.04	0.04	0.02	0.03	0.04	0.01	0.02
Ge al expense	0.12	0.14	0.11	0.08	0.12	0.07	0.09
Depreciation and stripping	0.26	0.37	0.29	0.20	0.29	0.14	0.20
Royalties	0.10	0.24	0.39	0.33	0.25	0.26	0.25
Taxes	0.04	0.05	0.06	0.07	0.05	0.04	0.05
Total mine cost	$1.64	$1.94	$1.92	$1.44	$1.77	$0.88	$1.23
Rail freight	0.30	0.40	0.40	0.99	0.46	0.80	0.67
Lake freight	0.68	0.59	0.77	0.77	0.70	0.77	0.74
Cost at Lower Lake ports	$2.62	$2.93	$3.09	$3.20	$2.93	$2.45	$2.64

vals on something which is really of economic service. Most such finds, it may be noted, are to be made in the report of the Commissioner of Corporations on the steel industry, which under happier conditions would have been recognized as a very remarkable monograph on an important industrial subject.

It is from this report that we can secure the most detailed data with regard to Lake ore costs, though as pointed out elsewhere there is need for caution in dealing with these data. The first table reproduced here has been rearranged slightly as to form, in order to put the various items of cost into what seems to be a more logical order and arrangement. It covers the average costs, during the years 1902 to 1906 inclusive, for a number of the more

TABLE 2.—COMPARISON OF LAKE ORE COSTS, 1902-06 AND 1907-10

	1902–1906	1907–1910
Tonnage covered by data	88,082,551 tons	88,833,156 tons
Labor costs	$0.43	$0.35
Other mining costs	0.21	0.20
Stripping and development	0.30	0.11
Depreciation	0.13	0.13
Royalties	0.25	0.29
Total costs at mines	1.05	1.08
Rail freight	0.70	0.74
Water freight	0.74	0.72
Total cost at Lower Lake ports	$2.49	$2.54
General charges	0.09	0.16
Total book cost	$2.58	$2.70

TABLE 3.—COSTS PER TON OF STEEL CORPORATION ORE, 1910

Ranges	Mesabi	Vermillion	All Lake ranges
Tonnage covered by data	17,875,059	1,338,110	23,010,216
Labor costs	$0.21	$0.57	$0.35
Other operating costs	0.50	0.49	0.52
Royalties	0.34	0.39	0.34
Total costs at mine	$1.05	$1.45	$1.21
Rail freights	0.80	0.99	0.74
Water freights	0.76	0.76	0.75
Total costs at Lower Lake ports	$2.61	$3.20	$2.70
General charges	0.18	0.17	0.18
Total book costs	$2.79	$3.37	$2.88

important companies mining iron ores in the Lake Superior district.

The second table requiring attention is one comparing the costs for the Steel Corporation and two other large companies for the two periods respectively 1902–1906 and 1907–1910. It is here presented as Table 2.

A third set of tables remains to be noted. These are combined here as Table 3, and cover the costs of ore to the United States Steel Corporation during the year 1910.

Purely for the sake of the interesting comparison with the foregoing records of recent costs in the Lake districts, it may be noted that Major Brooks gave[1] the following estimate of the cost of mining iron ore on the Marquette range in 1873, when the expensive square-set method of timbering was in use at most of the mines:

	Cost per ton	Percent of total cost
Dead work	$0.742	28.1 percent
Mining labor	1.050	39.8
Materials, tools, etc	0.313	11.9
Handling and pumping	0.413	15.6
Management	0.122	4.6
Total	$2.64	100.0 percent

Cost of Mining Red Ores.—The red or Clinton ores which form the backbone of the Southern iron industry probably show less variation in mining costs, at present, than do any other type of ore. The differences in conditions between the different red-ore mines are less than those between different brown-ore mines. The chief factor of difference, indeed, is thickness of ore bed, which does vary greatly from point to point; and most of the cost differences arise from this one variation. This uniformity in conditions and costs is due to the fact that most of the Southern red-ore mines have reached about the same stage of development. In almost all cases the leached soft ore has been removed; there is no longer any serious tonnage taken from open cuts along the outcrop; the underground ore is won in practically the same way at all mines, and so far no shaft operations have been opened.

In the early stages of the industry, while soft ores still showed

[1] Report Michigan Geol. Survey for 1873, p. 255.

in large tonnages along the outcrop, costs per ton must have been amazingly low. At a few points in Alabama and elsewhere there are still small tonnages of soft ore won by surface operations, either by hand or by scraper, and in these cases it is probable that the total costs chargeable to the soft-ore tonnage do not exceed twenty to thirty cents per ton. It is not only that this ore is easy to mine and handle, but that there are no development or maintenance charges to be considered. But these favorable conditions are now exceptional, and practically all of the red-ore tonnage now mined in the South comes at far higher cost.

The typical mine in the Southern red-ore districts is operated by a slope driven down the dip of the ore, from which entries right and left develop the ore on a room-and-pillar system. The slope may go down at angles of from 15 to 60 degrees, according to the dip of the ore in the particular district, and the workable ore may range from 2½ to 12 feet in thickness. These two factors—dip and thickness—are about the only differences between red-ore mines. The density of the ore and the character of the roof show surprisingly little difference, when once the mines have been driven down below the zone of surface leaching, so that the actual cost of breaking ore and timbering does not vary much from mine to mine.

Entirely aside from the factors which have so far been noted, and overshadowing them completely in their influence on the cost-sheet, are some differences in management and accounting practice which it is difficult to summarize. Two mines, located side by side, but belonging to different companies, may differ most remarkably in (1) the character, cost and standard of upkeep of the fixed equipment; (2) the *foresight* with which the ore is extracted; and (3) the manner and extent to which royalties or amortization are charged off. And the mine which is really managed in the best and most economical way is apt, over a short period, to show apparently the worst results so far as costs are concerned.

It is probable that the bulk of the Southern red-ore tonnage is now produced at total costs varying from seventy-five cents to slightly over one dollar per ton, at the mouth of the mine. Costs as low as fifty to sixty cents per ton have been reported from underground operations, but it is not likely that such low costs could be held for any length of time. On the other hand, where a

very thin seam is worked, as at some points in Virginia and elsewhere, the costs per ton may rise to $1.50 or more.

The following table appears as Table 9, on page 50 of the Report of the Commissioner of Corporations on the Steel Industry, Part III, 1913.

BOOK COSTS PER TON OF SOUTHERN RED ORES, 1902–1906

	1902	1903	1904	1905	1906	Average
Tons covered by table....	1,723,912	1,896,134	1,842,403	2,017,036	2,151,903	
Labor..................	0.47	0.51	0.49	0.47	0.50	0.49
Supplies and tools........	0.10	0.08	0.07	0.08	0.11	0.08
Repairs..................	0.05	0.05	0.07	0.06	0.07	0.06
General expense..........	0.02	0.01	0.02	0.02	0.02	0.02
Depreciation and royalty.	0.07	0.06	0.03	0.03	0.06	0.05
Total costs............	0.71	0.71	0.68	0.66	0.76	0.70

Cost of Brown-ore Mining.—Unlike the red ores which have just been discussed, the brown ores differ so widely among themselves that it is difficult to make general statements as to cost. The ores themselves differ widely in original richness, so that there are great variations in the amount of crude ore dirt which must be handled in order to produce a ton of merchantable ore. In addition, the ore deposits differ in size and attitude, so that there are also differences in the cost per ton of winning the crude material. Taken together, these variations in character of ore and deposit lead to wide ranges in mining costs between different districts, and even between different openings on the same property.

It will simplify matters a little if we make a rough division of brown-ore operations into underground mines and open cuts, and discuss the two classes separately. At present the bulk of the American brown-ore output is secured by steam-shovel work in open cuts; but in the Oriskany district of Virginia, at a few other points in the South, and at a number of small mines in eastern Pennsylvania and New Jersey underground mining is practised. In many instances the underground work is merely a development of old open-cut operations, and the shaft is located at the side of or in the old cut. Owing to the usual form and character of brown-ore deposits, the workings are commonly wet, and the roof is rarely good. Under these circumstances heavy allowances must be made for slides and falls, which reduce the economy of work. Perhaps the range of costs might be set at from fifty cents to one dollar and a half per ton of crude ore

hoisted. As against this high cost must be set the advantages that, since it is all hand work, it is usually possible to sort the material underground and so secure better grade, and that the work is practically independent of weather conditions.

In the open cuts which furnish the bulk of the brown-ore supply, most of the tonnage is usually extracted with the steam shovel, while hand labor is used for taking out small pockets of rich ore, for cleaning crevices, etc. Under ordinary conditions, there is less difference in the costs than might be expected by those accustomed to steam-shovel operations under better conditions. It must be recalled that a brown-ore deposit is usually very irregular in shape, in depth, and in the distribution of the rich ore within the deposit. All of these facts interfere with the economic use of the shovel; while even more important is the fact that most brown-ore deposits are so located topographically that it is difficult to secure the proper track development which insures good car handling. Unless we are dealing with a brown-ore deposit of exceptional areal extent, the problem is entirely different from that encountered on the Mesabi, and the results are correspondingly different, even when equal grades of supervision and operation are maintained.

At any given mine costs may vary tremendously throughout the year. If the operations happen to be at the moment in good ore, with banks of good height for shovel work, and if the weather does not interfere, the costs may be very low. The table below gives costs, per ton of concentrated ore, for a large brown-ore mine in Tennessee as published by Gillette. In each case the costs

COSTS OF BROWN-ORE MINING UNDER FAVORABLE CONDITIONS

	Steam shovel	Steam shovel	Hand work
Labor, excavating	$0.070	$0.070	$0.170
Labor, hauling	0.019	0.033	0.027
Drilling and explosives	0.010	0.017	0.019
Dumping	0.019	0.026	0.013
Track work	0.045	0.034 }	0.018
Blacksmith, repairs, etc	0.030	0.036 }	
Repair parts, etc	0.025	0.024	....
Coal, excavating	0.019 }	0.033	......
Coal, hauling	0.012 }		......
Iron, lumber, etc	0.008	0.007	0.002
Oil, waste, etc	0.003	0.004	0.001
Cost per ton washed ore	$0.260	$0.284	$0.250

cover a full month's operations. Columns 1 and 2 are for shovel work, column 3 for hand work in another part of the mine.

To these costs must be added, of course, the direct washing costs, which may have ranged between five and ten cents per ton of crude material. In the shovel work, the washing ratio was 4.6 to 1 for the first month quoted, and 5.6 to 1 in the other month. For the hand work, where they were handling a much better ore, the concentrating ratio was 2.4 to 1. Taking the washing costs at only five cents per ton of crude material passed through the washer, the total costs for the two steam-shovel examples would be forty-nine and fifty-six cents per ton respectively; while the hand work would total thirty-seven cents. If laborers and steam shovels were always in bonanza, there would be few difficulties in brown-ore mining. But when the matter is considered over longer periods, and proper allowances are made for lost time, prospecting, amortization, etc., it is probable that the average cost per ton of the American brown-ore output is now between \$1.00 and \$1.50.

BOOK COSTS PER TON OF SOUTHERN BROWN ORES, 1902–1906

Tonnage covered by table	1902	1903	1904	1905	1906	Average
	455,717	502,077	503,103	557,614	514,685	
Labor	0.62	0.61	0.61	0.59	0.70	0.63
Supplies and tools	0.06	0.03	0.05	0.09	0.09	0.06
Repairs	0.07	0.07	0.10	0.05	0.10	0.08
General expense	0.06	0.04	0.03	0.04	0.04	0.04
Depreciation and royalty.	0.06	0.05	0.04	0.04	0.05	0.05
Total	0.87	0.80	0.83	0.81	0.98	0.86

Cost of Mining Magnetites.—In attempting to summarize the costs of mining magnetites and other hard ores (specular hematite, etc.) in the eastern and southern United States, we meet with even more difficulty than in considering brown-ore costs. This arises from the fact that this particular group of ores, as developed in the Appalachian region, presents great diversity in such characters as affect operating conditions and costs. At the outset it can be recognized immediately that magnetite deposits differ

greatly in thickness of the ore-body, in its attitude or dip, in the character of the enclosing rocks, and in other features which directly influence the cost of breaking ore, timbering, hoisting, pumping, etc. But when all these matters have been considered, and we have arrived at some idea of what a ton of crude ore costs at the mouth of the mine, we find that the cost problem is still unsettled. For magnetites differ very remarkably in their original richness, and in the ease with which they may be concentrated to merchantable grade; and these differences of course affect the cost of salable ore very directly.

The average magnetite body now worked in the eastern and southern states is a relatively thin, vein-like mass, dipping at angles from 30 degrees to vertical; and is therefore worked by a steep incline or a shaft. It is also to be noted that it usually varies greatly in thickness and richness from point to point in the mine. It is true that there are important exceptions to this summary, for the Cornwall ores of Pennsylvania and many of the Adirondack ores of New York appear in thick masses, with prevailingly low dips, so as to offer opportunity for other methods of attack. But in general the magnetite problem involves breaking out a very hard ore, at considerable depth, and handling a large amount of water. Under these circumstances it is perhaps fair to assume that the mining costs will range from seventy-five cents to $1.50 per ton of crude ore placed at the mouth of the mine. To this must be added direct concentrating costs, and the total cost must then be charged against the tonnage of merchantable ore produced. It is probable that such total costs will range from $1.50 to $2.50 per ton of concentrates made.

An entirely different type of problem is encountered when it is proposed to quarry out a large mass of outcropping magnetite, probably of low grade, and concentrate it to salable ore. Such masses are known to exist at many points in the southern and eastern United States, and with the increasing demand for ore and the improvements in crushing and concentrating methods it is likely that their working will be taken up at numerous points in the near future. Under such conditions the mining or quarrying of the crude material may range in cost from twenty-five to fifty cents per ton, depending principally upon local conditions as to water, presence of joint planes, etc.

The actual work of breaking out crude magnetite ore in an open-cut mine in southeastern New York has been reported as giving costs which, reduced to a tonnage basis, are as follows:

Labor	$0.245
Explosives	0.032
Steam for drills	0.012
Repairs and supplies	0.006
Cost per ton, crude ore	$0.295

The following tables of cost are taken from the report of the Commission of Corporations:

COST PER TON OF EASTERN MAGNETITES, 1902–1906

Tonnage covered by table	1902	1903	1904	1905	1906	Average
	633,408	487,999	502,475	1,095,358	1,247,490	
Labor	0.24	0.38	0.34	0.35	0.42	0.35
Supplies	0.10	0.16	0.15	0.12	0.17	0.15
Materials	0.02	0.02	0.01	0.01	0.01	0.01
General expense	0.14	0.19	0.20	0.09	0.10	0.13
Depreciation	0.18	0.29	0.10	0.45	0.22	0.27
Royalty	......	......	......	....	0.04	0.01
Total cost	0.68	1.04	0.80	1.02	0.96	0.92

COST PER TON OF WESTERN AND CUBAN HEMATITES, 1902–1906

Tonnage covered by report	1902	1903	1904	1905	1906	Average
	905,275	883,274	527,873	1,018,297	1,246,066	
Labor	0.45	0.47	0.50	0.50	0.57	0.50
Supplies	0.16	0.17	0.22	0.24	0.28	0.22
Materials	0.14	0.09	0.03	0.06	0.04	0.07
General expense	0.10	0.11	0.12	0.09	0.11	0.11
Depreciation	0.41	0.15	0.04	0.31	0.32	0.27
Royalty	0.05	0.06	0.04	0.03	0.03	0.04
Total cost	1.31	1.05	0.95	1.23	1.35	1.21

Cleveland District, England.—The iron carbonate of the Cleveland district occurs, as described in another chapter, in

thick beds, dipping only slightly. The beds as worked range from almost 16 feet of workable ore down to 10 feet or so at the better mines. Originally opened by quarries along the outcrop, these were followed by slightly inclined tunnels underground. At present the larger portion of the tonnage is extracted from shafts located well back from the outcrop.

As to costs, the only data available are detailed enough, but do not relate to recent years. Both Kirchoff and Kendall furnish ample details for the years from 1890 to 1900 or thereabout; and since most of the labor payments in the Cleveland district are on a sliding scale, based on the price of Middlesboro pig metal, it will be possible to make sufficiently accurate estimates for our present purposes. As a further check, there are available official statistics as to the average value per ton of the ore from the Cleveland district. This appears to range, over a series of years, from two and one-half to four shillings per ton of crude ore at the mine, or say sixty cents to one dollar per ton.

All of the ore, it must be recalled, is calcined before charging to the furnace and the calcining kilns are located at the furnaces. Assuming that the average cost of crude ore, grading some 30 percent metallic iron, is about eighty cents, delivered at furnace, an additional charge of perhaps ten to twenty cents per ton of crude would cover fuel and labor for calcining. The average cost of ore at furnace is probably not far from three to three and one-half cents per unit during ordinarily prosperous years.

Lorraine-Luxemburg Ores.—The ores of the various portions of the Lorraine-Luxemburg basin differ greatly in thickness and cover, as will be seen from the descriptions in a later chapter. Both of these factors, of course, exert a large influence over mining methods and costs.

Along the eastern border of the field, and along some of the ravines entering it, open-cut mining is still possible in places. The tonnage worked by stripping and open-cut work is still large and, on the average, cheaply secured; but as the stripping becomes heavier costs are rising. Open-cut ore, under favorable conditions, can be mined and placed in cars for about twenty-five cents per ton.

In the southern portion of the field horizontal tunnels are driven in to the ore-body, while further west on the plateaus deep shafts

are in operation. For these underground workings total mining costs range from fifty to seventy-five cents per ton.

Taking the average grade of the ore into consideration, we may safely assume that the Lorraine-Luxemburg tonnage annually mined is produced at costs ranging between the limits of one and one-half and three cents per unit of metallic iron contained in the ore. This compares closely with the unit cost of our Birmingham red ores; and is somewhat above the average unit cost of Mesabi ore at mine. But, in comparing industrial values, it must be borne in mind that the Lorraine and Birmingham ores when once mined are practically at the furnace, while the Mesabi costs are increased by heavy transportation charges. A fairer comparison for Lorraine and Birmingham is the Cleveland district, previously considered.

Comparison of Principal Districts.—The data on mining costs which have been presented, incomplete and variable though they may be in some respects, are at least sufficient to permit certain broad comparisons between the ore costs of the principal iron- and steel-producing districts of the world.

The three producing districts whose competition is commonly understood as fixing prices are the Lorraine region, the Middlesboro district of England, and the Pittsburgh-Chicago area of the United States. To these certain others must be added, if we are to look beyond the present day for even a little way. The additional factors in world competition are Sydney, Nova Scotia; Birmingham, Alabama; and China. Another possible factor may in time become a reality, but it needs no discussion at present.

The six localities mentioned are all great steel producers, or may soon become so. They are all amply supplied with coal, with ore, and with markets. Of the six, four have water transportation which gives them export advantages; two, Pittsburgh and Birmingham, are inland points. Of the six, China is supplied with ridiculously cheap ore because of local labor conditions; Sydney, Lorraine, Middlesboro and Birmingham obtain a high-phosphorus ore at from two to three and one-half cents per unit of iron; Chicago and Pittsburgh obtain a dearer ore, low in phosphorus.

Of the four high-phosphorus centers, Lorraine has one advantage, for its ores yield a pig metal with sufficient phosphorus for

conversion by the basic Bessemer process; Middlesboro and Sydney will produce pig carrying 1.4 to 1.8 percent phosphorus; Birmingham pig will carry 1.0 percent or thereabouts.

As against the cheaper ores of the four centers just discussed, Chicago and Pittsburgh have the best local and non-attackable markets; and Pittsburgh has the cheapest and best fuel of all.

CHAPTER XII

FURNACE AND MILL REQUIREMENTS

In the preceding chapters it has been possible to discuss formation, prospecting and mining of iron ores without necessarily making direct reference to their chemical composition or marketability. It is now necessary, however, to turn our attention to these subjects, and to summarize their effects upon the commercial and industrial worth of different ores.

Before taking up the composition and concentration of iron ores it will be well to consider the uses to which these ores will be put, the requirements of the various processes by which they will be put into final market form, and the influence which these different requirements have upon ore values.

It will be understood that even the best of our commercial ores carry, as mined, considerable percentages of impurities; while the average ores now in use are very far from pure. Before taking up the question of concentrating such ores in order to remove part or all of the impurities, it will be of advantage to consider the operation and requirements of the blast-furnace, for the smelting process obviously fixes the extent to which concentration is necessary or desirable. It will be found that certain impurities can be removed so readily and cheaply in the furnace operation that it will rarely pay to attempt their previous removal by concentration; that other impurities are removable by the furnace, but only at considerable expense, and that still other impurities are practically irremovable by the furnace under commercial conditions. It is clear enough that if the ore contains impurities of either of these two last classes, it will pay to go to considerable expense to remove them before sending the ore to the furnace.

The Status of the Blast-furnace.—Practically all of the iron and steel products now in use have been derived ultimately from the reduction of iron ores in a blast furnace; and it is probable that for a long time to come the blast furnace will remain the most important source of commercial supply for the ferrous metals.

It is true that, under exceptionally favorable conditions, certain special products may even now be manufactured in other ways, but none of these other processes seem likely to become of great commercial importance in the near future. Under these conditions, since practically all of the iron ores mined will have to pass through the blast furnace, it seems best to limit the present discussion to that particular process, though at various points attention may be called to the different conditions and limitations which may be imposed by electric oro ther processes. On later pages, where the growth and development of the American iron industry is discussed, further details will be found regarding the changes in fuels and other matters affecting furnace practice. Here it will only be necessary to outline briefly the operation of the furnace, with special relation to the character of ore which it can handle economically.

Construction and Operation.—The modern blast furnace is essentially a steel shell, lined with fire brick. Its cross-section is circular at all levels, but its diameter varies at different portions of its height. As to dimensions, various furnaces now in use vary from 80 to 110 feet in height, and from 16 to 24 feet in maximum diameter.

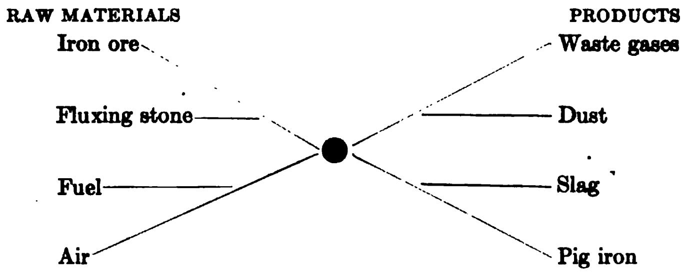
In converting iron ore into pig metal, the furnace requires four raw materials—ore, fuel, flux and air.

Of these four raw materials three are introduced at the top of the furnace—the fuel, the ore and the flux. The remaining raw material—air—is blown in at a point relatively near its base, after being (usually) heated and (occasionally) dried.

Under blast, the fuel attains a high temperature, the ore is reduced and melted, while the flux, the ash of the fuel and the earthy impurities of the ore combine as a fusible slag. The molten iron, sinking to the hearth, is drawn off at intervals, while the lighter slag floats on its surface and is tapped off at higher levels. Waste gases, with more or less dust, ascend from the heated zone. The relationship of the various raw materials and products may be expressed semi-diagrammatically as below.

The successful operation of the blast-furnace, from the purely physical standpoint, requires that it have adequate and satisfactory supplies of air, water, fuel, flux, ore and labor. In addition, in order that its operations may yield profits as well as pig iron, it will also require capital, intelligent management, transportation

routes leading to adequate markets, and rates which will enable it to place its product in those markets on at least a competitive basis.



If absolutely pure ores and fuels were available, the procedure would be simplified and the cost of manufacture greatly reduced. For example, if we could secure any quantity of absolutely pure ore—that is to say, an iron oxide mineral containing nothing but iron and oxygen—and if pure carbon free from ash were available for fuel, there would be no necessity for adding any fluxing material, and the quantity of fuel used would be simply that required to reduce the iron to the metallic state and to put it into a molten condition. This would be a much smaller quantity per ton of product than is now used at the best plants, and costs would be reduced correspondingly.

But with conditions as they are, the best commercial ores contain impurities, and the best fuels will leave more or less ash after burning. These conditions have two effects on the furnace process. They make it necessary to employ some fluxing material, and they increase the fuel required by the process. As all of these factors react upon the ore question, it will be well to discuss briefly the relations of fuel and fluxing material, before taking up the matter of ores.

Blast-furnace Fuels.—Fuel is used in the blast furnace primarily to furnish the heat required to smelt the ore; and if a pure native iron were employed as ore this would be the only reason for using fuel. But with ordinary impure ores, the fuel must serve two additional purposes, for it must act to reduce the iron oxide or carbonate to the metallic state, and it must afford sufficient additional heat to fuse the entire charge, so that flux and ore may react upon each other chemically. Under existing conditions, therefore, fuel is needed to supply both heat and reducing

action, a fact which must not be lost sight of when electric smelting methods are under discussion. Even when the heat for fusion can be supplied by electricity, carbon in some form will still be required to reduce the iron oxides to metallic iron; so that the use of the electric furnace does not do away entirely with the necessity for adding charcoal or coke to the charge.

Three types of fuel have been, at different times and in different localities, largely used in iron smelting. These are respectively charcoal, coal and coke. In a later chapter detailed figures will be given concerning their respective importance at different dates. Here it need only be said that coke is now by far the most important of the world's fuels; and that at present about 98 percent of the American iron production is made by its use, as compared with some 1 percent made with anthracite coal, and 1 percent made with charcoal. For all practical purposes, attention may therefore be confined to coke, when modern blast-furnace fuels are under discussion.

Limiting the discussion in this fashion, it may be said that even the best cokes now available bring considerable impurities into the furnace, and that in future the average grade of coke used may be expected to decrease quite rapidly, for the pick of the British cokes, the Connellsville of Pennsylvania and the New River of West Virginia are far from being inexhaustible. Smelting a 60 percent Lake ore with Connellsville coke was a far different thing from using a 30 to 36 percent Alabama or Luxembourg ore with such cokes as are locally available; and these facts alone are sufficient to point out that pig iron must in future be a dearer commodity than it is at present.

The coke is bought and used for the sake of the fixed carbon it contains, which furnishes both heat and reducing action. But in addition to this constituent, commercial coke brings into the furnace a certain amount of silica, alumina, iron oxide, lime, sulphur, phosphorus, etc., and all of these must be taken care of in the furnace operations. It will be seen that the impurities contained in the ash of the coke are substantially the same that occur in ordinary iron ores. The coke rarely brings in any new problem in metallurgy; it simply accentuates the old ones.

Fluxing Materials.—In smelting iron ores a certain portion of the impurities contained in the ore may be volatilized by the heat, and driven off as gases. This is the case, for example,

with whatever moisture, carbon dioxide or organic matter which the ore may have contained; for all of these impurities will readily disappear under the influence of the high temperature of the furnace. A part of the sulphur brought in by the ore may also be removed in this simple fashion, but not so readily nor so completely as the impurities previously mentioned. On the other hand, it will be seen that the more important impurities contained in the ore and coke can not be so driven off by simple heating, but on the contrary will fuse with the iron. Silica, alumina, lime, magnesia, phosphorus, and all the metallic impurities will act in this way; and this fact introduces the necessity for the employment of fluxing materials.

It is of course necessary to separate the molten iron from the non-volatile impurities which have fused with it. In order to accomplish this, the mixture charged into the furnace must contain such relative proportions of lime, magnesia, silica and alumina that these elements will combine to form a light fluid slag, which can be drawn off from on top of the heavier molten iron. Occasionally an ore is found whose impurities are so balanced that the ore is naturally self-fluxing or self-slagging; but this is a very rare case. In by far the majority of instances the ore will carry too much of one element, so that to get a proper slag it is necessary to add to the charge some fluxing material containing a counter-balancing amount of the other slag-forming elements. For example, the usual ore will carry too much silica and alumina; and in this case it will be necessary to use some basic material (limestone, dolomite, etc.) to balance the excessive amount of acid elements in the ore. If, as in rarer cases, the ore naturally carries too much lime, it would be necessary to add silica in some form—preferably by using a very siliceous ore as part of the charge.

The Chemical Limitations of the Blast Furnace.—From the preceding summary of blast-furnace operation, which is necessarily brief, it will be seen that the furnace can remove certain impurities from the ore very readily and cheaply; that it can remove certain other impurities, but only with difficulty or at considerable direct cost; and that a third class of impurities are either entirely resistant to the furnace, or could only be removed by it at a prohibitive expense. These facts have, of course, a very direct influence on the matter of ore concentration; for they

fix the expense to which we can go to remove or lessen any impurity before charging the ore into the furnace.

These results on concentrating practice may be summarized as follows: (1) Water, carbon dioxide and organic matter are removed by the blast-furnace practically by the use of its own surplus heat, so that their removal by the furnace does not involve any direct expense. If the ore mine is located at or very near the furnace, there is therefore no reason why we should attempt to remove these impurities by preliminary treatment. If, however, the mine and furnace are widely separated, so that freight or haulage costs are of importance, it will often pay to remove the volatile impurities at the mine so as to save paying freight on them.

(2) Silica, alumina, lime, magnesia and other rock-forming impurities fall in the second class. This group can be removed by the furnace, but only in the form of slag. Their removal, though simple enough, therefore involves a direct additional cost, for each pound of such impurity contained in the ore requires an additional amount of fluxing material to balance it, and an additional amount of fuel to fuse the impurity and the added flux. The extent to which it will pay to remove such impurities is determined by the cost of coke, freight rates, etc.; and in any given case can be calculated in advance quite precisely.

(3) Phosphorus, sulphur, and the metallic impurities (manganese, chromium, etc.) fall in the third class. In this case the blast furnace is practically powerless to remove or seriously lessen the impurity; for under normal operating conditions impurities of this class do not pass out with the slag, but combine in part or entirely with the molten pig metal. It is perfectly true that the furnace *can* be so operated and charged as to remove the bulk of the titanium and sulphur, and much of the manganese; but in making the blast furnace do this work we are using it for something outside its proper and economical sphere of action. If therefore the pig metal is to be used in a further process requiring absence or low percentages of sulphur, phosphorus and metallic impurities, it will pay to go to considerable expense to remove such impurities from the ore by concentration previous to charging it into the furnace.

Other things being equal, the rapidity and completeness of chemical reactions are increased by diminishing the size of the

particles involved, and by placing them in closer contact. If therefore we regard the operation of the blast furnace as being simply an attempt to produce certain chemical reactions, by the aid of heat, in the most economical manner, it would seem that the maximum efficiency would be attained if the furnace were charged with an intimately mixed mass of pulverized coke, ore and flux. From a purely theoretical viewpoint, this might be true, but certain practical difficulties stand in the way of using such a charge, though the tendency of modern practice seems to be in that direction.

Regarded simply as a metal-producing appliance, the modern blast furnace at its best has reached close to its possible limit of efficiency, and we can hardly expect further great improvements from this standpoint. Of course considerable advance in average practice can fairly be expected, for there are many localities where the furnace itself, its method of operation, or the preparation of the charge could be better than at present.

The improvements in furnace results are to be looked for in another direction, and will consist in careful utilization of the slag and of the various products issuing from the top of the furnace. The rising current of gas carries off a number of valuable products—heat, volatilized compounds and dust. All of these can be recovered and utilized. The four main types of future improvement in furnace practice are therefore likely to be along the lines respectively of:

a. Utilization of heat carried off in various forms.
b. Recovery of alkalies, cyanide, etc., from volatilized compounds.
c. Recovery of valuable constituents of dust.
d. Utilization of slag.

All of these are feasible, and all are practised at some point now.

The Utilization of Pig Iron.—The iron produced in the blast-furnace is *pig iron*. Because of its chemical impurities and physical structure, pig iron is not serviceable as a final product, but is to be regarded as merely an intermediate stage in the process of manufacture. With only trifling exceptions, all of the pig iron produced by blast furnaces goes either:

1. To the foundry, for remelting and conversion into *cast-iron* products;

2. To the puddling mill, for purification and conversion into *wrought-iron;* or,

3. To the steel furnace, for conversion into *steel.*

There have been great changes during the past century, and even during the past two decades, in the relative proportions of the total pig-iron tonnage which are used in these three ways. With the rapid growth of the steel industry, the percentage of the total pig-iron output converted into steel has risen rapidly, while that sent to the puddling mill has fallen to almost negligible proportions. The foundry consumption has grown in absolute amount, but not so rapidly as the steel-furnace consumption. At present perhaps five-sixths of the total American output of pig iron is converted into steel, and almost all of the balance is used in the iron foundry.

The Various Steel Processes.—There have also been great changes in the relative importance of the various steel-making processes. In order to make this point clear, a word of explanation as to the relations of the various steel-making processes may not come amiss. Detailed consideration of these technical matters can not be taken up here, but for our present purposes the following summary may be sufficient.

Disregarding the relatively unimportant output of steel produced by the crucible, electric and other minor methods, it may be said that practically all of our commercial product is made by treating pig iron either in a *Bessemer converter* or in an *open-hearth furnace.* Generally speaking, the steel made in a converter can be produced at lower cost, and in larger quantities compared with the cost and size of the plant. On the other hand, the open-hearth process is more completely under control of the operator, and the product can be made to conform more closely to his requirements as to composition. So much being understood, it must now be noted that *each* of these general methods—the open hearth and the converter or Bessemer—can be used in either of two ways:

1. As an *acid* process, when the pig-iron used is already low in phosphorus; or

2. As a *basic* process, when high-phosphorus pig iron is to be used.

When pig iron is made in the blast furnace, the metallic iron absorbs all of the phosphorus which was present both in the ore

and in the fuel. Phosphorus is a highly undesirable element in steel, and it is clear that the only two ways in which a low-phosphorus steel can be produced are:

(a) To start with ores very low in phosphorus, thus making a low-phosphorus pig iron. This can be converted into steel either in a Bessemer converter or in an open-hearth furnace. In either case, since the iron is already low in phosphorus, no special care need be taken to reduce this element, and the lining and charge of the furnace or converter may be siliceous or *acid*. When starting with low-phosphorus ores and pig iron, therefore, we may adopt either the *acid Bessemer* or the *acid open-hearth* steel processes.

(b) When, however, we start with ores high in phosphorus, all of this element is taken up by the pig iron; and it is necessary to reduce it greatly during the conversion of the iron into steel. To be efficient for this purpose the converter or open-hearth furnace must have a basic (instead of an acid or siliceous) charge and lining; and the process adopted may therefore be either the *basic Bessemer* or the *basic open-hearth*

The four processes which have been named above account for practically all of the heavy steel production of the world, for other processes are used merely for special products of minor importance so far as tonnage is concerned.

Nothing that has been said concerning the rapid development in the use of the basic steel processes all over the world must be allowed to minimize the fact that their adoption is not a matter of choice, but of necessity. There is nothing particularly attractive about basic methods, and with the one exception below noted they are more expensive, ton for ton, than the corresponding acid processes. Phosphorus, in the quantities in which it usually occurs in either ores or pig iron, is a peculiarly undesirable element from every point of view; and it costs money to remove it. To use the words of a distinguished engineer regarding the purification of water supplies, we would prefer innocence to repentance; and it is only because low-phosphorus ores are everywhere becoming scarce that the basic processes are growing in importance.

There is, however, one very important exception to this summary of the subject, as noted in the previous paragraph. Phosphorus in the pig always increases the cost of making steel;

but if the pig contain *over* a certain amount of phosphorus, the resulting slag will be rich enough in phosphoric acid to be merchantable as a fertilizer. At a certain point, therefore, phosphorus actually becomes a money-maker for the plant. The basic Bessemer plants of Germany rely largely on this fact for their profits; and some of our own Southern iron districts will come to it in time.

ALLOWABLE PHOSPHORUS IN PIG FOR VARIOUS UTILIZATIONS

Acid open-hearth—less than 0.05 percent
Acid Bessemer—less than 0.10 percent
Basic open-hearth for normal process, not over 1.50 percent and preferably, not over 1.0 percent: for special processes, 1.50 percent and over.
Basic Bessemer—at least 1.50 percent, preferably over 2 percent.
Foundry iron—wide range, according to special use of the iron.

Factors Influencing Metallurgic Value.—The preceding summary of the chemical limitations of the blast furnace, taken in connection with some easily understood physical considerations, enable us to group the principal factors which exert an important influence on the metallurgic value of iron ores in the following six classes:

1. Richness in iron content.
2. Presence and amount of metallic impurities.
3. Composition of the gangue—as to silica, etc.
4. Presence of sulphur and phosphorus.
5. Presence of volatile impurities.
6. Physical characteristics of the ore.

CHAPTER XIII

COMPOSITION AND CONCENTRATION OF IRON ORES

In an earlier chapter it was stated that certain definite minerals form our chief ores of iron, and that theoretically these different minerals have certain definite chemical compositions. In the present chapter we must consider how far these theoretical conclusions are qualified in actual practice, for it will be found that iron ores, as mined, always contain impurities. Often, in fact, the amount of waste matter contained is so great, or of so injurious a type, that for industrial purposes it is necessary to lessen or remove it by concentration before the ore can be profitably used in the blast furnace. Attention must therefore be turned to the natural impurities which accompany iron ores, to the degree to which these impurities may be economically lessened or removed, and to the general methods of concentration which are available for such removal.

THE IMPURITIES OF IRON ORES

In Chapter III the iron minerals available for use as ores have been considered from the mineralogical stand-point solely, as pure minerals, and no attention has been paid to the impurities which, as a matter of fact, always accompany them. In the present section these accompanying impurities will be discussed in the detail which is demanded by their industrial importance.

The Universal Presence of Impurities.—Wherever iron ore is mined on a commercial scale, the product of the mine invariably contains various impurities. The presence of some of these will be obvious enough on simple inspection, while others will require more or less careful chemical analysis for determination of their presence and amount.

In most cases a portion at least of the impurities in the mined ore are removed before the ore reaches the furnace, but even then the amount remaining is notable. The ordinary range of ores, as charged to-day to the furnaces in different parts of the United

States, may be from 90 to 50 percent in iron oxide and the average is now close to 70 percent. In other words, our ores normally carry into the furnace, in addition to their metallic iron and the oxygen combined with it, from 10 to 50 percent of waste matter. Under these conditions it is therefore evident that a close study of the impurities in iron ore is of importance not only to the miner but to the furnaceman.

Sources of the Impurities.—So far as their source or origin is concerned, the impurities commonly present in iron ores may be conveniently grouped in three classes, according as they are (1) derived from the gangue or country-rock, or (2) are derived from minerals intimately associated with the iron mineral, or (3) are essential constituents of the iron mineral itself. In the last case, the propriety of the use of the term "impurity" is of course doubtful, but it is convenient to cover such instances as the carbon dioxide of iron carbonates and the combined water of brown ores, both of which are removable by simple treatment.

From the furnaceman's point of view, all of the above classes are equally impurities, if present in the ore supplied to him. The chief practical reason for separating them into the three groups above named is the fact that the ease with which the ore may be freed from any given impurity depends largely upon the group in which the impurity falls.

Character of the Impurities.—It is of course entirely conceivable that any chemical element might appear as an impurity in iron ore. In practice, however, it is found that certain elements and compounds do appear with considerable frequency, while others are so rare as iron-ore impurities that they may be neglected both in analysis and in discussion.

There are, in fact, some fifteen or twenty foreign constituents which do appear in commercial iron ores with sufficient frequency to be worth considering here. Of these, some are almost universally present in considerable quantity, while others are distinctly rarer but are still common enough, or important enough in their effects, to require consideration.

For example, any iron ore, even of high grade, will usually contain appreciable percentages of moisture, silica and alumina. Iron ores of certain types may also contain rather large amounts of combined water, carbon dioxide, organic matter or lime. Almost any ore will contain smaller, but appreciable, percentages of

sulphur, phosphorus, manganese, titanium, magnesia, potash and soda. Certain ores may carry notable amounts of copper, chromium and nickel.

For convenience in discussing the character and effect of these impurities it will be best to group them in such a way as to bring together those which are nearly related. The following grouping is imperfect, but satisfactory enough for our present purposes:

Metallic—Manganese, titanium, chromium, nickel, copper.
Alkaline—Lime, magnesia, potash, soda.
Acid—Silica, alumina.
Volatile—Water, carbon dioxide, organic matter.
Special—Phosphorus, sulphur.

The groups above noted can now be briefly described in the order named.

Metallic Impurities.—Of the metallic impurities, manganese is almost universally present in iron ores. In more than trifling percentages, however, it is probably associated most frequently with the brown ores. The other four metallic impurities—titanium, chromium, nickel, and copper—are in general associated with the magnetites and specular hematites, rather than with the brown ores or carbonates. This, however, is due chiefly to the different methods by which these two types of ore have commonly originated; so that in rarer but still notable cases we may find brown ores high in chromium and nickel, and magnetites or hematites high in manganese.

Alkaline Impurities.—With regard to lime, magnesia, potash, and soda, which have here been grouped as alkaline impurities, three different sets of associations with iron ores are found, according to the origin of the ores. In the Clinton hematites, for example, high percentages of lime and lesser amounts of magnesia occur as part of the calcareous matter which forms a normal portion of the ore. In the brown ores the four alkaline impurities are present usually in small percentages as ingredients of the clay commonly associated with the ore, though at times lime and magnesia will be present in undissolved fragments of limestone. In ores associated with igneous or metamorphic rocks, as the magnetites and massive hematites usually are, all of the alkaline impurities are frequent, and in this case they are usually traceable to the rock which encloses the ore-body.

Acid Impurities.—Silica and alumina are invariably present in iron ores, whatever the kind, grade, or origin of the ore may be. In the brown ores, the Clinton ores, and the carbonates, the silica and alumina which are present ordinarily represent the essential constituents of clay. In the magnetites, hematites, and other ores when associated with igneous or metamorphic rock, the silica and alumina are normally present as constituents of quartz, feldspar, hornblende, or other silicate minerals.

Volatile Impurities.—Of the volatile matters which are found in iron ores, water is present in two forms. In all ores it occurs as simple moisture, mechanically held by the fragments of ore. In the brown ores, or hydrated iron oxides, combined water is also present, as an essential constituent of the iron mineral.

Carbon dioxide is, of course, an invariable and essential constituent of the carbonate ores. It is rarely found in any of the other types of iron ore, except in the Clinton and other oölitic ores. This exception, however, is one of great importance owing to the scale on which these ores are now worked in Newfoundland, Lorraine and the United States. It may therefore be pointed out that the carbon dioxide reported in analyses of Clinton ores is combined with the lime, and not with the iron of the ore, and that this is also true of part of the Lorraine ores.

Organic matter is a frequent impurity of the carbonate ores, particularly where these ores are associated with coal beds or with carbonaceous shales. It is rarely found in any of the other types of iron ore, except occasionally in some of the more porous brown ores, such as those which have originated as bog or spring ores.

Special Impurities.—Phosphorus and sulphur require special mention among the impurities found in iron ores. This is not because of the quantity in which they occur, for it is but rarely that more than very small percentages are present in any ore. Their importance is due entirely to the injurious effect which they have on the iron and steel made from the ore, and to the difficulty or impossibility of entirely freeing the ore from their presence.

Distribution of Impurities in Typical Ores.—The manner in which the different impurities which have been above noted are associated with the different classes of iron ores can be best exemplified by a series of complete analyses of typical ores. The following table contains analyses which are fairly representative

in this respect. Of the analyses presented, numbers 1, 2, 3, 5 and 6 are quoted from Vol. X, Reports Tenth Census, so that they are entirely comparable throughout, both as to methods of sampling and as to analytical methods. As this volume contains no complete analysis of a hard Clinton ore, analysis No. 4 has been added from another source.

ANALYSES OF TYPICAL IRON ORES

	1	2	3	4	5	6
Metallic iron	49.66	62.65	53.60	38.71	50.04	38.75
Manganese oxide	0.04	0.25	0.23	0.22	n. d.	0.99
Titanium	......	......	......	......	......	......
Chromium	......	......	......	......	......	......
Nickel	......	......	......	......	......	......
Lime	1.19	0.26	2.23	10.51	0.25	5.65
Magnesia	16.33	1.58	0.52	n. d.	0.25	2.40
Potash	0.12	0.38	0.17	n. d.	0.14	n. d.
Soda	0.22	n. d.	0.01	n. d.	0.11	n. d.
Silica	10.81	4.42	10.52	19.34	11.23	2.92
Alumina	1.11	2.37	45.58	3.39	4.99	0.53
Carbon dioxide	0.28	0.12	0.09	8.26	0.13	36.11
Organic matter	0.01	0.01	0.04	n. d.	0.25	} 0.71
Combined water	0.89	1.12	1.69	n. d.	10.20	
Moisture	0.16	0.19	1.02	0.60[1]	0.42	
Phosphorus	0.007	0.018	0.641	0.35	0.108	0.121
Sulphur	0.538	0.011	0.085	0.04	0.179	0.262

Analysis No. 1. Magnetite. Tilly Foster, New York.
" " 2. Hematite. Chapin, Michigan.
" " 3. Clinton hematite, soft. Attalla, Alabama.
" " 4. Clinton hematite, hard. Birmingham, Alabama.
" " 5. Brown ore. Tecumseh, Alabama.
" " 6. Carbonate ore. Clarion County, Penna.

All the analyses are of specially good ores, of their respective classes. Poorer ores would of course show still higher percentage of impurities, but of essentially the same kind.

[1] Calculated.

From the preceding discussion it must be obvious that ores, as mined, are far from being the pure minerals considered by the mineralogist. Attention must now be paid to the economic effects of these impurities, and to the methods which may be employed to reduce them.

CONCENTRATION

At present most of the Lake Superior ores, and all of the Birmingham district red ores, are shipped to the furnaces as mined, without any concentration or treatment. On the other hand, practically all of our magnetic ores and brown ores are concentrated before being sent to the furnace. Concentration methods are adapted either to save freight or nonessential ingredients of the ores, or to remove injurious impurities. As a matter of fact, both reasons are frequently operative in the same instances.

The term concentration, as here used, is intended to cover all methods of raising the grade of iron ores, or of lessening their impurities, prior to their use in the blast furnace. It is obvious, of course, that the decrease or entire removal of any impurity will necessarily raise the grade of the ore that is left, so that there is no real reason for drawing a fine distinction between the two aims of concentration. As a matter of fact, however, we always do make such a distinction, mentally at least, between them. When an ore is treated for the purpose of getting rid of a relatively large amount of water, sand, clay or gangue-rock the natural thing is to fix the mind on the raise in grade which results. When, on the other hand, it is treated in order to remove or lessen an already small amount of an active impurity like sulphur or phosphorus, the concentration is thought of as an attempt to lower impurities.

The methods which may be used for these purposes depend, of course, on both the character of the ore and the character of the impurities to be removed. As noted in an earlier section of this chapter, the impurities which may be associated with an iron ore differ in their origin, in their relations to the ore itself, and in their own chemical and physical characteristics. All of these factors must be taken into account when concentrating methods are under consideration. For our present purposes a very convenient classification is that following:

1. *Volatile impurities*, due to the physical or chemical inclusion of volatile compounds. Includes ordinary moisture, combined water (in brown ores), organic matter, carbon dioxide (in carbonate ores), etc. Sulphur and zinc, when present, are also volatilizable, though less readily and completely than water and the carbon compounds.

2. *Gangue impurities*, due to inclusion of portions of the associated or country rock. Includes silica, alumina, lime, magnesia and alkalies present; sulphur when present as visible crystals of pyrite; phosphorus when present as visible crystals of apatite (lime phosphate).

3. *Intimate impurities*, due to impurities in the iron mineral itself, or to the presence in the ore of minute particles of gangue material. Includes usually all of the titanium and chromium that may be present; often much of the sulphur; and usually most of the phosphorus.

It will be seen that the classification above used gives some clue as to the methods which may be adopted for the removal of the various impurities. The volatile impurities may obviously be removed or lessened by heating the ore. In this case the process is often named specifically, according to the chief object of removal, as

Drying, to remove water.
Roasting, to remove sulphur.
Calcining, to remove carbon dioxide.

The second class of impurities—those derived from the gangue or country rock, are removable by physical methods, because in this case the ore and the impurity usually differ greatly in physical characteristics, and are physically separable. In carrying out this separation, we may depend on differences in size, in gravity, or in magnetic force. In some brown-ore deposits, where lumps of ore are mixed in with clay or fine sand, the ore lumps can be separated effectively by screens or by plain log washers. When the difference in size is not so great, or where ore and impurity are so intimately associated that preliminary crushing is necessary, jigs or tables have to be added to the washer to secure effective concentration. Finally, in the case of the magnetite ores, it is possible to separate the magnetic ore from the non-magnetic impurity by magnetic concentration.

The third class of impurities named, those in which the iron and the impurity are intimately associated in the ore itself, are practically unremovable in ordinary commercial practice; and the possibility can only be considered when justified by exceptional circumstances.

Of course, whenever concentration is necessary, it makes an additional cost which must be charged against the ore. This must be justified by compensating decreases in freight and handling costs, by increased furnace efficiency, or by improvement in grade of metal produced.

The following data on the specific gravity of various iron ores, and of the minerals and rocks most likely to be associated with them, will be of service in determining the feasibility of methods of gravity concentration.

Magnetite	5.2 maximum	Slates	2.7 to 2.9 range
Hematite	5.2 maximum	Granites	2.66 average
Brown ore	4.8 maximum	Traps	2.7 to 3.1 range
Iron carbonate	3.9 maximum	Quartz	2.5 to 2.8 range
Shales	2.4 average	Calcite	2.5 to 2.8 range
Sandstones	2.0 to 2.7 range	Apatite	3.18 to 3.25 range
Clays	1.9 average.	Pyrite	4.8 to 5.2 range
Limestones	2.3 to 2.9 range		

Actual Importance of Concentration.—The subject of ore concentration is so interesting theoretically, and so intensely important to a few ore fields whose grade is close to the commercial margin of profit, that we are apt to overestimate its actual importance in the world's trade. As a matter of fact, concentrated ores are not an important factor to-day in the iron industry, and except in certain areas it will be many decades before they become the leading source of supply.

It may be well to substantiate these statements by summaries of actual conditions in the more important ore fields of the world.

Lake Superior District.—The sandy ores of the western portion of the Mesabi range are now being washed to decrease silica and raise the iron percentage; the Atitokan ores of Canada are roasted to lower sulphur; and a few mines have recently begun to dry their ores to lower moisture and save on freight. Of these three treatments, the last may increase to some extent; and the percentage of washed ore may hold its own under normal conditions, or

increase heavily if the demands upon the Lake Superior region become much greater.

Lorraine-Luxemburg District.—In this, the second most important ore producing district of the world, no concentration of any type is practised; and none appears to be practicable.

Birmingham District.—The red ores of the Birmingham district are not concentrated in any way. Unless ore requirements increase enormously, the chances of any serious concentrating practice are poor.

Southern U. S. Brown Ores.—Occurring in clays and sands, these are usually washed in log washers, and often crushed and jigged. In various brown-ore districts the crude mined product may carry from 5 to 20 percent metallic iron; by concentration this is usually brought up to a "washed ore" grading 45 to 50 percent iron.

Carbonate Ores, Great Britain.—Of the two general types of carbonate ores used in various British districts, the nodular ores are hand-picked at mouth of mine. All carbonates are roasted in kilns to remove water, organic matter and carbon dioxide.

Magnetites, New York and New Jersey.—As the supply of available high-grade lump ore is small, magnetic concentration is practised at almost every mine. When the magnetite is granular, ores carrying as low as 22 percent metallic iron can be concentrated economically; with platey magnetites, the fine crushing necessary renders concentration almost valueless. The ordinary grade of concentrating ore ranges from 30 to 35 percent iron, crude; it is carried up to 55 to 63 percent iron in the concentrate. Sulphur, phosphorus and titanium are often decreased incidentally.

Spanish Hematites.—Except for hand picking of some ores, and fairly close grading at the mine, no concentration is practised.

Magnetites of Pennsylvania.—Mostly from contact deposits of the Cornwall type, the Pennsylvania magnetites are normally high in sulphur, and are roasted or sintered to decrease this constituent.

Wabana Hematite, Newfoundland.—Ore as mined grades 48 to 50 percent iron; and most of the shipments to Sydney are crude ore of this grade. Perhaps half the total output is picked, on a belt, at the mine, grade being raised to 51 to 53 percent metallic iron.

Cuban Brown Ores.—The brown ores of the Santiago district are

low grade and very high in water. To improve grade and physical character they are sintered before shipment.

Pacific Coast Ores.—The hematites and magnetites along and near the Pacific Coast of both North and South America are mostly from contact deposits. They are commonly high-grade lump ores at the surface; but frequently sulphur increases in lower levels so as to require roasting.

Brazilian Hematites.—Not shipping yet, but sufficient supply of high-grade lump is known to exist, and concentration will be unnecessary.

Scandinavian Magnetites.—Some of the Swedish fields still have large tonnages of high-grade lump ore available. But on the average magnetic concentration is becoming steadily more of a factor.

CHAPTER XIV

PRICES, PROFITS AND MARKETS

The chapters immediately preceding have dealt with the costs at which ore may be produced. The question which remains to be considered relates to the price at which it will probably be sold. In spite of all the publicity which has been given to this subject recently, there seem to be certain general principles which have not been adequately discussed. For some years past one particular phase of the subject—the proper relation between Lake and Birmingham ore values—has been of really serious interest; and one has but to recall the hopeless muddle in which geologists, engineers, metallurgists and lawyers succeeded in involving this question, in order to realize that there is still room for discussion of the elements of price-fixing.

COSTS AND PRICES

The cost of an ore, delivered at any given furnace, is made up of a number of elements some of which are frequently overlooked or slighted. On the other hand, the price which can be realized for an ore is not entirely a matter of chance or of individual preference, as might be supposed from examination of current literature on the subject. It is fixed within certain definite limits, and even its variations withn these limits are determined by conditions which can be at least stated, even if they can not be accurately evaluated in advance. The present section will deal briefly with these two phases of ore valuation—the elements entering into costs, and the larger factors which limit prices.

Factors Included in Total Costs.—Part of the difficulty has arisen because of differences in selling practice in different regions. To understand this, it will be best to examine the elements which go to make up the cost and the price of iron ore at various stages in its journey, from the time it simply lies unworked in the ground until the time it is converted into merchantable metal.

The following schedule summarizes these factors in their normal order.

FACTORS IN ORE COSTS	Per ton of ore
a. Original cost per ton of ore in the ground	$
b. Accumulated interest per ton to date of shipment.	______
c. Actual cost of ore to owner..............................	
d. Profit on ore land investment............................	______
e. Value of ore to owner, or royalty value	
f. Cost of mining..	
g. Profit on investment in mining plant, capital, etc............	______
h. Selling price of ore at mouth of mine	
i. Cost of transporting ore to furnace.........................	
j. Profit on investment in transportation properties............	______
k. Selling price of ore at furnace	
l. Profit *per ton of ore* to be made by converting into pig	______
m. Actual value of ore, per ton, to the furnace.................	

It will be seen that there are at least six methods in which cost or value of ore could be stated. Of these, the forms lettered *a*, *e*, *h* and *k* are used quite commonly.

Absolute Price Limits.—It will be convenient, before going further with the subject, to fix upon the absolute minimum and maximum prices which can be reached by iron ores sold in an open market.

The *minimum* price at which an ore can be sold, provided the mining company expects to remain in the business, will be reached during periods of extreme business depression. It will be close to the actual cash costs of mining, forgetting or putting aside such items as depreciation which though proper are not pressing.

The *maximum* price that can be realized will be secured during some period of business prosperity, and usually near the close of such period. It will be made when an independent furnace company, in order to deliver iron, buys ore at a price which does not allow for a proper conversion profit.

It is of course obvious that such prices, both minimum and maximum, are abnormal, in the sense that they can not be long continued and that they can not affect very large proportions of the total tonnage. Nevertheless, in every season of acute depression or wild expansion, we will find that certain contracts have come pretty close to these theoretical limits.

The preceding fixing of absolute limits has this advantage, that it enables us to place limits of price per unit of metallic iron

in the ore. For example, we know from the data given in Chapter XI that a number of very important districts can mine ore at a sheer cost of two to three cents per unit of contained iron; and we may therefore take some such figure as this for the lowest price at which ore could be sold in any large market. On the other hand, a rough calculation of possible furnace profits at different prices of pig and ore will show that we might set our absolute maximum price for ore at something like ten cents per unit of iron. A furnace paying over this price could not make money even during a boom year in a high-priced district.

Unless new cheaply mined and well located ore fields are discovered, we may therefore assume that no large tonnage of ore can be sold under two and one-half cents per unit or thereabouts. At the other extreme, unless the world becomes accustomed to paying a good deal more for its pig iron and steel, no large tonnage of ore can ever bring over ten cents a unit. Later study of actual ore prices will show that, as a matter of fact, the bulk of the ore tonnage sold in open markets anywhere in the world ranges in price between perhaps four and one-half and eight and one-half cents per unit. The average of these two figures is six and one-half cents per unit; while the average we would have deduced on a purely theoretical basis would have been six and one-fourth cents per unit.

The *average* price realized for ore must necessarily fall somewhere between the minimum and maximum possibilities outlined above. Since the furnace company is commonly in a stronger industrial and financial position than the mining company, the average will probably be closer to the possible minimum than to the possible maximum. But, over a long series of years, it must be sufficiently high to allow for a reasonable rate of profit to the miner, on all the capital employed in his business, after deducting all proper costs and charges. In this connection a *reasonable rate of profit* does not mean 4 or 5 or 6 percent, for no one would take up mining unless the average rate of profit yielded were at least equal to that which could be secured from other enterprises of equal financial hazard.

Effect of Metallurgic Value.—If we confine our attention to one given ore district, supplying one given furnace region, it will be substantially accurate to say that the metallurgic value of the different ores determines their relative price. That is to say,

of two Lake ores delivered at Pittsburgh the relative prices will be determined by such matters as percentage of metallic iron, phosphorus content, and physical structure. This fact is well understood, and in Chapter XII there has been some discussion of the way in which these different chemical and physical factors influence values through their different effects in blast-furnace and steel-mill practice.

Unfortunately, starting from this perfectly sound assumption that within a given furnace district metallurgic values determine relative prices, we have had to deal with very erroneous lines of reasoning. It has been assumed, for example, that it should be possible to compare two different districts, and to determine from comparison of the metallurgic values of their ores what the prices of those ores should be. This is an utterly unsound idea, as can be seen when the matter is studied in a general way, without introducing the words Pittsburgh and Birmingham into the discussion at too early a stage.

In the sections immediately preceding we have seen that ore prices, within a certain market area, are limited in two directions. They can not regularly fall below the actual cost of the ores, plus a reasonable profit on all the operations involved in getting the ores to the furnace. They can not, on the other hand, rise above the point at which the furnaces make little or no profit by using them. The matter of metallurgic value, it will be seen, enters only very indirectly into the question.

DIVISION OF THE PROFITS

The total profit derived from the mining and use of a ton of ore is divided between several parties who have taken part in the process—the land owner, the miner, the transportation company, and the furnace. Some attention must therefore be given to the manner in which this division of profits takes place, and to the factors which determine what share should go to each of the parties in interest.

The Parties in Interest.—A ton of ore, carrying let us assume 50 percent metallic iron, will ultimately be converted into close to half a ton of pig iron, worth perhaps seven dollars. On this basis the iron in the ore has a gross ultimate value of fourteen cents per unit. But at first glance it is obvious that this value is the result of a long series of operations, and that a number of items of cost may be deducted before we can arrive at any idea of profit or net value. Finally, it is probable that these operations

have been carried on by separate business interests, so that the net profit will be divided among several claimants.

Reduced to its simplest form, we may consider that four different interests are involved in the matter. One party owns ore land which originally cost something, and which has accumulated carrying charges in the course of years. In addition, this land owner will naturally expect a profit on his part of the transaction. This portion of the total profit it is convenient to distinguish as *Royalty*, in whatever form it may be paid.

The second party to the transaction is the mining company. This contributes an investment in mining equipment and working capital, and expects a profit above all costs.

The third party handles the transportation of the ore from mine to furnace. It also uses equipment and capital, and expects profits.

Finally, the furnace takes the ore at a price, and converts it into pig iron. Sold in this form, or in more highly finished condition, it may be assumed to have reached an ultimate consumer. The furnace company, of course, also has used money and plant, on which profits are expected.

If the ore trade is to be on a normal basis, each of the four parties interested in the series of transactions must, on the average, make fair business profits. This must be taken for granted, but in discussing the division of the total profits we may for our present purpose, disregard the transportation company as a factor in the matter. Under ordinary conditions, we may assume that transportation charges will be fixed at such rates as will move the traffic, and that they will not fluctuate with ore or iron values. The transportation company does not, therefore, have the same direct interest in the question of values as have the land owner, the miner and the furnaceman.

Smelting or Furnace Profits.—Of the total profits derived from the mining and smelting of iron ore, the lion's share will usually go to the account of the furnace and mill. This is a commercial necessity, under present conditions, and arises from the greater financial strength of the smelting companies. It is true that they have heavier fixed investments per ton of product than do any of the mining companies, and even when mine and furnace receive the same rate of profit on their investment the greater share, expressed in cents or dollars per ton, would be due to the

furnace. But it is probable, though it would be difficult to prove decisively, that the furnaces yield on the average a larger *rate* of profit than do the mines.

The gradual exhaustion of old sources of ore supply will tend to raise the prices paid for ore in any given furnace district; and the same tendency will be shown if commercial conditions lead to marked increase in smelting capacity. On the other hand, such tendency to a rise in ore prices will be checked by the opening up of new and important sources of supply. The interaction of these factors will determine, in the long run, what prices will be commonly paid for ore.

Mining Profits.—Deducting transportation charges, the money paid for ore by the furnaces is left to be divided, in some way, between the miner and the land owner. An outline of certain factors which affect mining profits will be at least suggestive.

The *average* rate of mining profit in any given mining district is not affected to any serious extent by mining costs. This may at first sight seem to be an erroneous conclusion, but it is clear enough that, in a free market, any unusual advantage which the mining district as a whole may possess will, in the long run, be counter-balanced by reduction in the prices at which the ore will be sold, or by a rise in the rate of royalty paid to the land owner. Of course low costs, as between mine and mine in the same district, will affect profits markedly; but not for the district as a whole.

Other factors remaining the same, the mining profits will be increased by either a rise in the price obtained for ore, or by a fall in royalties; and they will be decreased by contrary movements in these regards. Now, higher ore prices mean that the annual output is becoming smaller, relative to the demand. On the other hand, low royalties imply that there are large ore reserves available, in proportion to the annual demand upon them. It will therefore be unusual to find a district in which these two factors can operate favorably to mining profits, at the same time; for normally an increased demand for ore will be met by increased draft on the ore reserves.

Under ordinary conditions, mining profits will be low when there are extensive ore reserves in a district, owing to the competition of the numerous separate mining operations which may be expected to go into the business. If, however, there are financial

or physical difficulties in the way of numerous mining operations, mining profits may be high even when very large reserves are available. The Wabana field may be cited as an instance where physical difficulties operate to limit the maximum annual output which may be reached.

Royalties.—The term *royalty*, as used here, covers all payments made to owner of the land or mine, as distinct from mining profits.

The average rate of royalty for any given district is not determined to any large extent, by the grade or iron content of the ore. This fact does not seem to be generally understood, for there have been long disquisitions on the supposedly unfair differences in royalty or purchase rate, between the ores of two different districts. *Within* a district, on the contrary, metallurgic value does obviously and properly influence royalty rates; for clearly unless a high-grade ore has some unusual mining costs, it can bear a higher royalty rate than a low-grade ore from the same district.

But when two different ore districts are compared, it can be seen that the chief factor in average royalty rate is not metallurgic grade or value, but the relative scarcity of the ore left in the ground, compared with the annual draft on the ore reserves of the respective districts. The best instance of this has been quoted in an earlier chapter (Chapter XI) but may be summarized here for convenient reference. It is afforded by comparison of royalty or purchase rates in the southern United States as against similar rates in the Lake Superior district. At first glance it might seem that the wide differences between the royalties or purchase prices of the two districts are due to differences in grade of ore. But further consideration shows that the ruling factor is not this, but the fact that the Lake reserves are very small compared to the annual shipments from that district, while the Southern reserves are enormous compared to the present annual draft upon them. If these conditions ever change, royalty rates in the two districts will become more nearly equalized.

ACTUAL MARKETS AND PRICES

The preceding discussion has dealt with the elements involved in the fixing of prices, and with the factors which determine how the total profits are to be divided among the various

parties at interest. With this as a basis, it will be profitable to take up some consideration of the two great ore markets now existing, and of the prices which ores actually attain in these markets.

Prices of Lake Superior Ores.—Of the world's ore markets, the one covering the largest tonnage from one district is that established for Lake Superior ores. Of course the bulk of the Lake Superior ore output is used by iron and steel interests mining their own ores, and this portion of the annual output does not reach any market. But the remainder is merchant ore, and this fraction may now amount to one-quarter of the entire Lake output—or to possibly ten to fifteen million tons per annum. Prices for these merchant ores are quoted and reported regularly, so that the record is quite complete. As in every other commercial transaction, there are undoubtedly minor fluctuations in price within the year, for small portions of the tonnage, but these may be disregarded here.

The price of Lake ores for the coming season is fixed usually in the late winter or early spring. It is based upon current anticipations as to the probable course of the iron and steel market, so that ore prices fluctuate more or less in accord with pig-iron prices. It is easy to overestimate the importance of this concordance, however, for of course the price of ore is one element in the cost of pig iron, so that the relationship is not entirely prophetic, but in part a matter of cause and effect.

For forty years after shipments began the price of Lake ores ranged, on the average, irregularly downward. The minimum was reached during the 1893–1897 depression; and since that date there has been a slight recovery on the average.

In considering the history of Lake Superior ore prices, as in dealing with any series of prices over a long term of years, allowance must be made for the great changes which have taken place, from time to time, in the purchasing value of the dollar in which these prices are expressed. To disregard this very important factor is to introduce serious errors into our conclusions. This is particularly noticeable in dealing with prices during the decade or so from the commencement of the Civil War to the resumption of specie payments; for during this period actual changes in selling conditions produced far less effect upon nominal prices than did the wide changes in the value of gold. The apparently

high prices of ore during some of these years did not mean really high returns to the miner, for everything which he purchased was paid for, at correspondingly high prices, in the same depreciated currency.

With this caution, which is specially necessary in dealing with prices covering over sixty years of changing dollar values, we may take up the records as they stand.

The following table contains data on Lake Superior ore prices from 1856 to 1913 inclusive. For the years prior to 1890, the prices quoted are taken from several sources, all authoritative, but not strictly comparable. For example the prices from 1856 to 1874 inclusive are for standard old-range Bessemer ore, as given by the Michigan Commissioner of Mineral Statistics; from 1875 to 1889 inclusive, they are for Republic and Champion ores, which normally sold somewhat higher than the standard used for the preceding years. An average deduction of fifty to sixty cents per ton, during the years 1875–1889 would probably put the data on a basis exactly comparable with those given for the 1856–1874 period. From 1889 to date the data are quoted from the Iron Trade Review.

PRICES OF LAKE SUPERIOR IRON ORE, 1854–1913

	Old range Bessemer	Mesabi Bessemer	Old range non-Bessemer	Mesabi non-Bessemer	Iron Prices: Valley Bessemer	Iron Prices: Foundry Iron No. 2
1856	$8.00	....	....	....	....	....
1857	8.00	....	....	....	....	....
1858	6.50	....	....	....	....	....
1859	6.00	....	....	....	....	....
1860	5.25	....	....	....	....	....
1861	5.25	....	....	....	....	....
1862	5.25	....	....	....	....	....
1863	7.50	....	....	....	....	....
1864	8.50	....	....	....	....	....
1865	7.50	....	....	....	....	....
1866	9.50	....	....	....	....	....
1867	10.50	....	....	....	....	....
1868	8.25	....	....	....	....	....
1869	8.25	....	....	....	....	....
1870	8.50	....	....	....	....	....
1871	8.00	....	....	....	....	....
1872	9.00	....	....	....	....	....
1873	12.00	....	....	....	....	....
1874	9.00	....	....	....	....	....
1875	7.75	....	....	....	....	....

PRICES OF LAKE SUPERIOR IRON, 1854–1913. (*Cntinued.*)

	Old range Bessemer	Mesabi Bessemer	Old range non-Bessemer	Mesabi non-Bessemer	—Iron Prices— Valley Bessemer	Foundry Iron No. 2
1876	7.50	....	....	....	....	....
1877	7.00	....	....	....	....	....
1878	6.50	....	....	....	....	....
1879	7.00	....	....	....	....	....
1880	10.00	....	....	....	....	....
1881	10.00	....	....	....	....	....
1882	10.00	....	....	....	....	....
1883	7.50	....	$4.75	....	....	....
1884	6.00	....	4.50	....	....	....
1885	5.75	....	4.00	....	....	....
1886	6.25	....	4.50	....	....	....
1887	7.00	....	5.00	....	....	....
1888	5.75	....	4.00	....	....	....
1889	5.50	....	3.75	....	....	....
1890	5.50	no sale	5.25	no sale	$22.15	$18.15
1891	4.50	no sale	4.25	no sale	15.15	15.00
1892	4.50	no sale	3.65	no ale	15.00	13.65
1893	3.85	$3.00	3.20	no sale	12.65	12.15
1894	2.75	2.35	2.50	no sale	9.65	9.65
1895	2.90	2.19	2.25	$1.90	9.40	9.40
1896	4.00	3.50	2.70	2.25	12.40	11.15
1897	2.60	2.25	2.15	1.90	8.35	8.40
1898	2.75	2.25	1.85	1.75	9.55	9.80
1899	3.00	2.40	2.15	2.00	10.30	9.75
1900	5.50	4.50	4.25	4.00	24.15	22.15
1901	4.25	3.25	3.00	2.75	16.15	14.40
1902	4.25	3.25	3.25	2.75	15.90	15.90
1903	4.50	4.00	3.60	3.20	21.50	21.65
1904	3.25	3.00	2.75	2.50	13.35	13.15
1905	3.75	3.50	3.20	3.00	15.50	16.00
1906	4.25	4.00	3.70	3.50	17.25	17.25
1907	5.00	4.75	4.20	4.00	21.50	21.50
1908	4.50	4.25	3.70	3.50	16.00	15.00
1909	4.50	4.25	3.70	3.50	14.75	14.25
1910	5.00	4.75	4.20	4.00	19.00	17.25
1911	4.50	4.25	3.70	3.50	15.00	13.75
1912	3.75	3.50	3.00	2.85	14.25	13.25
1913	4.40	4.15	3.60	3.40	17.25	17.50

The prices quoted in the preceding table are for ores carrying a certain percentage of iron, delivered at Lake Erie ports. Now, as the average grade of the ore shipments from the Lake region has decreased slowly, there have at intervals been changes in the percentage of iron contained in the ore used as a basis for

prices. These changes of course affect the comparison, and the following table, quoted direct from the *Iron Trade Review*, is serviceable in calling attention to the real changes in price per unit of iron.

PRICE PER UNIT OF IRON, 1903–1913

Fluctuations of iron-ore prices expressed in values of units of iron in natural state.

	Old Range		Mesabi	
	Bessemer, cents	Non-Bessemer, cents	Bessemer, cents	Non-Bessemer, cents
1903..............	7.94	6.82	7.05	6.06
1904..............	5.73	5.21	5.29	4.73
1905..............	6.61	6.06	6.17	5.66
1906..............	7.50	7.01	7.05	6.60
1907..............	9.09	8.16	8.64	7.77
1908..............	8.18	7.18	7.73	6.80
1909..............	8.18	7.18	7.73	6.80
1910..............	9.09	8.16	8.64	7.77
1911..............	8.18	7.18	7.73	6.80
1912..............	6.82	5.83	6.36	5.53
1913..............	8.00	6.99	7.55	6.60

The average prices per unit of iron, for the eleven years covered by the preceding table, are as follows:

Old Range Bessemer	7.76 cents
Mesabi Bessemer	7.27 cents
Old Range non-Bessemer..................	6.89 cents
Mesabi non-Bessemer.....................	6.47 cents

For a long and fairly representative period, therefore, we may assume that the bulk of the merchant tonnage of Lake ores sold, at lower Lake ports, at around seven cents per unit of contained iron; more for low-phosphorus ores and less for high-phosphorus ores.

The Atlantic Ore Market.—The Lake ore market has been said to be the largest in the world, so far as tonnage sold from a single district is concerned. But it is not so complicated, so large in total tonnage, or so widely competitive, as that existing along the North Atlantic coasts of Europe and America. It might be further added that this Atlantic market seems likely to attain greatly increased importance in future.

It is difficult to make any very precise estimate as to the actual tonnage of iron ore sold in the Atlantic coast markets during a normal year. It amounts, however, to considerably in excess

of twenty million tons annually. Of this about half is taken by Germany, and almost half by Great Britain. The remainder is bought chiefly by furnaces in Belgium and the United States; for the Sydney plants, though using imported (Newfoundland) ore, take it from their own mines and so do not enter the general market.

The mines which furnish this large merchant tonnage are located in widely separated countries. Sweden and Spain furnish the bulk of the British and German imports, if we disregard ore brought into Germany from French Lorraine. Newfoundland, Cuba, Algiers, Russia, the Adirondacks and other areas of less importance furnish smaller portions of the Atlantic merchant tonnage. Details as to production, exports and imports of ore will be found tabulated in various chapters of Part III of this volume, and it is unnecessary to present exact figures here. What we are chiefly concerned with now is that here is a market taking twenty million tons or more a year of iron ore; taking it from many competitive sources, and using it in many competitive furnaces. It is unquestionably a far wider and freer market than the Lake market can ever be. And, since most of the furnaces which it supplies are on tidewater (or on navigable rivers or canals), the Atlantic ore market is the keystone of the world's export trade in iron and steel products.

Within the Atlantic market the range in ore prices is wide, varying from year to year according to the condition of ocean freights, as well as varying more definitely according to grade and character of ore.

The part played by the ocean freight rate is important, but too variable to be more than approximately stated here. With the exception of such long hauls as the proposed Chilian and Brazilian ores will require, it may be said that during a long series of years the ocean-borne iron ore of the world pays a freight rate ranging between three and seven shillings per ton. Few hauls ever fall below the minimum quoted; while little important tonnage moves at a higher rate than the maximum stated above, even in years of brisk ocean traffic. These limits may be reduced, for convenience, to a unit basis; they would range between perhaps one and one-half to three cents per unit of metallic iron.

The total price realized at Atlantic coast markets, including

of course the ocean freight, may range between five and one-half and eight and one-half cents per unit of iron. The lowest price is secured by ores with undesirable physical structure, with phosphorus between difficult limits, or with other unusual constituents. The higher unit prices are realized by ores high in iron, and with phosphorus either below the acid Bessemer limit or above the basic Bessemer limit.

CHAPTER XV

THE EFFECTS OF TIME ON VALUATION

In Chapter IX, where the basal factors in valuation were summarized, it was noted that the element of time must be considered in attempting to arrive at the present value of a large ore property. This is true, not only in the sense in which it is now commonly understood, but in an entirely different and (to some extent) opposing sense. If we are to come to a correct conclusion as to the present valuation to be placed on an ore property, we must not only allow a discount for the time which will be taken in exhausting it and realizing the total profits, but we must take into consideration the factors which are likely to increase ore values in future.

Determination of Total Present Value.—After the engineer has determined (1) the available tonnage of ore on the property and (2) the average value or profit per ton of this ore, he is prepared to undertake the final determination of (3) the total present value of the property.

In case the total tonnage is so small that it will all be worked out in the course of the first year after purchase, the total present value of the property is of course found by simply multiplying *tonnage* by *value per ton.* But except in the case of very small properties, the complete extraction of the ore will necessarily be spread over a number of years, under which circumstances the problem is no longer a matter of simple multiplication—a fact which is often overlooked.

To put this matter in its simplest terms, it is obvious that a dollar which will not be earned or received until 1950 has not the same present value as a dollar receivable during the current year. A ton of ore which will not be mined until 1950 can not, accordingly, be considered to be as valuable as a ton which will be mined and sold or used during the present year. In order to arrive at the total value of a large ore property it is therefore necessary to discount the value of the tonnage according to the length of time for which certain portions of it will remain unmined.

It will perhaps be clearest if the matter is put in the form of a specific instance. We may assume, therefore, that we are dealing with a property containing 1,000,000 tons of iron ore; and that the owner expects either to have this mined on a royalty of twenty-five cents per ton, or if he mines it himself to receive net profits of the same amount per ton. In either case the total amount which will ultimately be received from the property will be $250,000. But, unless the entire 1,000,000 tons is to be mined in the first year, it is obvious that the actual *present* value of the property will be something less than $250,000, for a series of payments to be made over a series of years must be discounted in order to determine their present value. All of this is simple enough, but it is rarely understood how very heavily the more distant payments must be discounted, and how great a difference there often is between total and present value.

In order to understand the importance of this factor, it is necessary to recall that we are dealing with a problem in compound discount; and that, as will be later noted, we have to assume a rather high rate of interest because of the character of the security offered. Even at 6 percent the discounting effect is very great, as is shown by the following table.

TIME VALUES AT 6 PERCENT

Years	Compound interest	Discount	Years	Compound interest	Discount
1	1.0600	0.943	10	1.7908	0.558
2	1.1236	0.890	15	2.3965	0.417
3	1.1910	0.840	20	3.2071	0.311
4	1.2625	0.792	25	4.2919	0.233
5	1.3382	0.747	30	5.7435	0.174
6	1.4185	0.705	35	7.6861	0.130
7	1.5036	0.665	40	10.2858	0.097
8	1.5938	0.627	50	18.4190	.....
9	1.6895	0.592	..	....	.....

Proper Carrying Charge.—In figuring amortization against ore reserves, as well as in calculating the present value of large reserves, there seems to be frequently shown a tendency to assume an unfairly low interest rate. It is assumed, for example, that because a steel company may, during years of easy money, float its first mortgage bonds on a 5 percent basis, or perhaps somewhat better, that ore calculations may be made on the same basis. Indeed we have recently had one prominent instance—the so-

called Hill ore lease—where 4 percent seems to have been accepted as the basis for calculation.

Taking everything into consideration, it does not seem justifiable, in considering long-time ore calculations, to assume a carrying rate of less than 6 percent. It does not seem probable that, under any ordinary conditions in the American money market, any steel company whatever could secure money at a lower rate if ore reserves were the only security offered. We have, indeed, one very decisive case of this kind available for consideration. In 1907 the Spanish-American Iron Company, a subsidiary of the Pennsylvania Steel Company, offered a series of 6 percent bonds, secured by its Cuban ore deposits, on a basis which permitted public sale at 98½. These bonds were guaranteed, principal and interest, by the parent company; and were part of an authorized issue of five million dollars, against which six hundred million tons of ore were pledged. Of course 1907 was a year of dear money throughout, but in view of the ample security and incidental guarantees of various sorts which characterized this issue, it does not seem probable that a straight ore bond could be floated by any company, even in an average year, at a lower rate.

The Great Northern ore lease is, in this connection, of peculiar interest, though it can hardly be considered as making a sound precedent. It will be recalled that in the Hill lease the ore price increased 4 percent per annum. This would seem to have been an entirely false basis for calculation, and the effect of the unjustifiably low interest rate is shown markedly when the ore prices are discounted on a proper basis. The base-ore nominally valued for the first year at eighty-five cents per ton; but when values, are re-calculated on a 6 percent basis, it will be found that this means a real "present value" of forty to sixty cents a ton, according to the probable duration of the ore reserves covered by the lease. The value per ton placed upon the Hill ores was in reality, therefore, much less than the face or nominal value which has been so frequently discussed.

It might further be noted, in relation to proper interest rates, that the main ore reserves now coming into sight are located in areas where local money conditions favor high rates. Brazil, Cuba, and even Alabama and Texas, are not areas of normally cheap money; and local financing of a straight ore security would probably mean rates ranging from 8 percent upward. So that,

all things considered, we are not likely to under-estimate the matter much by assuming 6 percent as the minimum carrying charge or discount rate. Even at this rate the discounting effect is more than might casually be expected. If ore is being mined on a royalty basis of twenty-five cents per ton, the royalties for the tenth year of the lease can be given a present value of only fourteen cents per ton; while those to be earned in the fortieth year have a value now of only about two and one-half cents a ton. In other words, a property which can not be worked out in forty or fifty years does not derive much additional present value from the ore still in the ground at the end of that time. It is this fact which puts a purely commercial limitation on the acquisition of *excessive* ore-reserves, as will be pointed out in a later chapter.

Possible Changes in Ore Values.—The operation above discussed—the discounting of total value to allow for the years spent in extraction—has an air of precision and finality which makes it very attractive to a certain type of mind; and accordingly we find that many estimates are now so discounted. It is true that those who insist on precise results can go no further than this stage of refinement; but it is also true that those who prefer general accuracy to misleading precision must still consider another factor in the problem.

Up to this point we have assumed, as is the common practice, that the average value per ton will remain fixed during the productive life of the property. For short periods of time, this assumption is reasonably correct, and it would be simply hair-splitting to consider any other possibility if the property is to be exhausted within five or ten years. But if the property promises a life of twenty, or fifty or one hundred years—and there are such properties still in the market—the matter takes on an entirely different aspect.

In the opinion of the writer, the principal factors which must be considered in this connection may be summarized as follows:

1. There is little probability that any large supply of ore grading above 50 percent metallic iron still exists unknown in the United States. So far as magnetites and hematites are concerned, the inferior limit might be safely lowered to 40 percent, and the above statement would still hold, for it is highly improbable

that any unknown field exists containing one hundred million tons of magnetite or hematite of even this grade. But with regard to brown ores the case is different, for there are probably large tonnages of these ores, grading from 40 to 50 percent, still unprospected.

2. There is every reason to suppose that brown ores of the type now shipped from the north shore of Cuba will be discovered, in really immense tonnages, elsewhere in the Caribbean area. These and the Wabana ores may ultimately control the location of the export steel mills of the United States, but they will not serve to decrease the values of higher grade interior ores.

3. The supply from Canada may be increased from sources now unknown, but the chief possibilities for large new ore fields in Canada are so located that they will hardly affect the world's ore trade.

4. The high-grade supplies from Sweden, Norway, Spain, Algiers and Morocco will continue for years to come, but will hardly extend their present markets.

5. South America, Africa and Asia may, and probably will, yield immense new tonnages; but until the manufacturing industries and general civilization of the world seek new centers these distant deposits can not affect values to any calculable extent.

The preceding summaries merely embody the writer's judgment on the points at issue, and are of course open to discussion. But if they are substantially correct, two deductions must inevitably be drawn from them.

I. Domestic ores grading above 50 percent metallic iron and so located as to reach interior markets are not likely to be subjected to new and serious competition. As the domestic reserves of this grade are limited, ores of this type will increase in value steadily and perhaps rapidly. Under these circumstances, the increase in value per ton will in most cases, counter-balance the allowance made in discounting the total value to present value; and therefore a company owning a fifty-year supply of such ores is probably fairly entitled to value them somewhat as if the entire tonnage could be used in the present year.

II. Domestic ores grading between 50 and 35 percent metallic iron are likely to be subject to competition from at least three sources: the further development of the Caribbean

and Wabana fields, the discovery of new brown-ore areas, and the marketing of low-grade magnetites. This competition is likely to prevent ores of this grade from showing a very rapid increase in value; and in dealing with large holdings of this type of ore it is probably safest to discount their value according to their probable length of life.

PART III.—IRON ORES OF THE WORLD

CHAPTER XVI

THE IRON ORES OF THE UNITED STATES

Before taking up the description of the various iron-ore producing regions of the United States, it will be well to get some idea both as to the rank of the country, as a whole, among the ore-producers of the world and as to the general tendencies which may exist in the American ore trade itself. The present chapter may therefore be regarded as a preliminary discussion, covering these general points of interest. Except where otherwise noted, the statistics on which the discussion is based are those published annually by the United States Geological Survey. They have been rearranged where necessary to better serve our present purpose.

Status of the United States.—For a number of years past the United States has been both the leading consumer and the leading producer of iron ore, its consumption and output being approximately two-fifths of the world's totals. In ore production Germany ranks second and Great Britain third, ordinarily followed by France, Spain, Russia, Sweden and Austria in the order named. The three leading producers—the United States, Germany and Great Britain—usually produce together about three-quarters of the world's output of iron ore. In later chapters details will be given as to the world's annual output of iron ore.

Of the leading ore producers, Spain and Sweden export most of of the ore mined and the same may be said of Cuba, Newfoundland and Algeria, all of which furnish about one million tons yearly for export. On the other hand, Belgium, which has a very low rank as a producer of iron ore, is a consumer on a considerable scale. Great Britain is a heavy importer of ore, and Germany also takes considerable foreign ore.

The United States is practically self-contained in this regard, for the exports of ore almost balance the imports. This condition, however, is not likely to continue, and it is probable that in

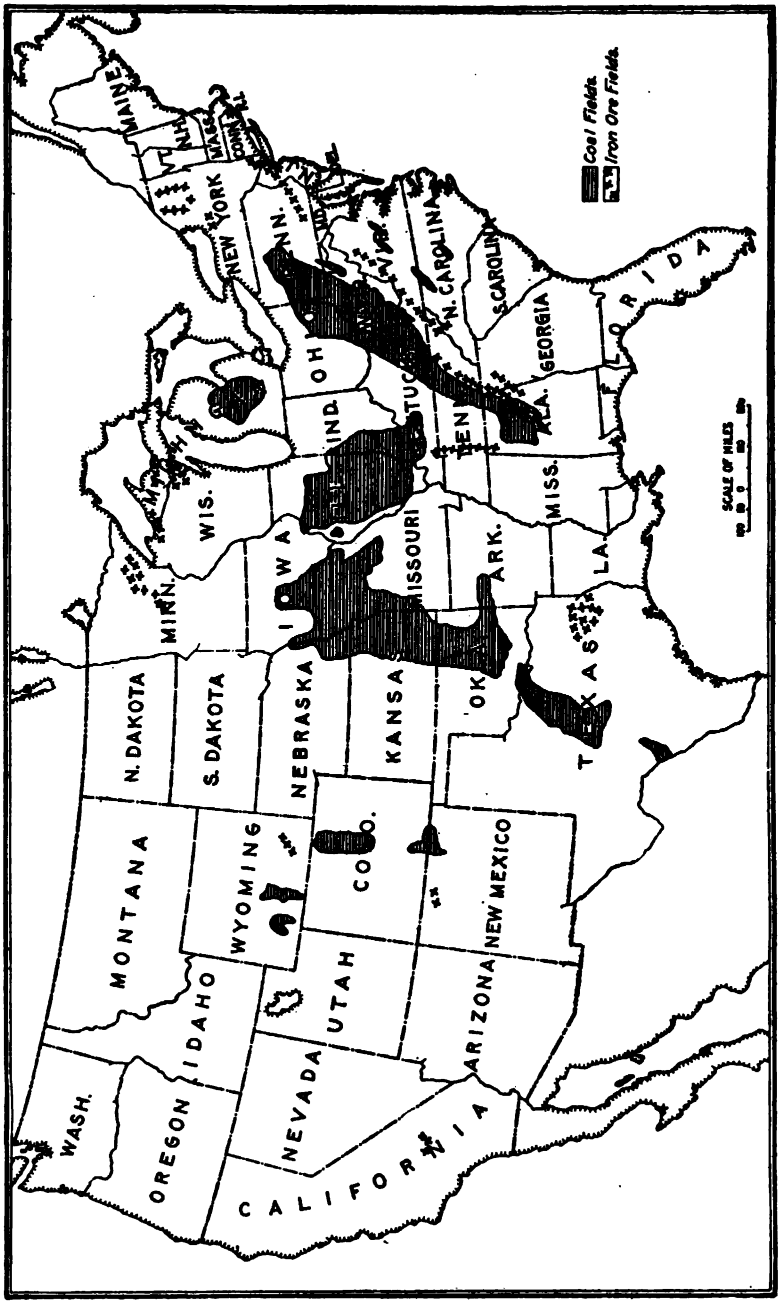


FIG. 21.—Iron-ore districts and coal fields of the United States.

future imported ores will make up a more important proportion of the consumption than they have in the past.

American Iron-ore Output, 1860–1912.—Detailed statistics relative to the production of iron ore in the United States are not available, except for a few of the census years, back of the year 1889, when the United States Geological Survey first began collection of data on this subject. The following table contains all the definite statistics relative to the total iron-ore production of the United States, for such years as are covered by reliable data. Later the present writer furnishes estimates for the earlier years, based on the pig-iron production, concerning which we have more complete information prior to 1889.

In the table following, the data for the years 1860, 1870 and 1880 are taken from reports of the federal census for those years; the figures from 1889 to the present date are from the annual statistical volume issued by the United States Geological Survey.

PRODUCTION OF IRON ORE IN UNITED STATES, 1860–1910

Year	Long tons	Year	Long tons
1860	2,873,460	1901	28,887,479
1870	3,831,891	1902	35,554,135
1880	7,120,362	1903	35,019,308
1889	14,518,041	1904	27,644,330
1890	16,036,043	1905	42,526,133
1891	14,591,178	1906	47,749,728
1892	16,296,666	1907	51,720,619
1893	11,587,629	1908	35,924,771
1894	11,879,679	1909	51,155,437
1895	15,957,614	1910	56,889,734
1896	16,005,449	1911	43,876,552
1897	17,518,046	1912	55,150,147
1898	19,433,716	1913	....
1899	24,683,173	1914	....
1900	27,553,161		

Imports of Iron Ore.—The following tables, taken from the statistical volume of the United States Geological Survey, give details as to the import movement in iron ores.

The first table gives the total imports of ore into the United States, for each year from 1872 to date. Prior to 1872 there had been irregular and small imports, mostly from Canada, of which no record was kept by the government.

IMPORTS OF IRON ORE, 1872–1912

Year	Quantity	Year	Quantity	Year	Quantity
1872	23,733	1885	390,786	1899	674,082
1873	45,981	1886	1,039,433	1900	897,831
1874	57,987	1887	1,194,301	1901	966,950
1875	56,655	1888	587,470	1902	1,165,470
1876	17,284	1889	853,573	1903	980,440
1877	30,669	1890	1,246,830	1904	487,613
1878	28,212	1891	912,864	1905	845,651
1879*a*	150,197	1892	806,585	1906	1,060,390
1879*b*	284,141	1893	526,951	1907	1,229,168
1880	493,408	1894	167,307	1908	776,898
1881	782,887	1895	524,153	1909	1,694,957
1882	589,655	1896	682,806	1910	2,591,031
1883	490,875	1897	489,970	1911	1,811,732
1884	487,820	1898	187,208	1912	2,104,576

a Fiscal years end. *b* Calendar years begin.

As regards the source of these imports, details are found in the table on page 183. It will be seen that Cuba is by far the most important contributor; followed by Sweden, Newfoundland, Canada and Spain in the order named.

Exports of Iron Ore.—The ore exported from the United States so far as recorded is given in the following table, also taken from the Geological Survey publication. It may be noted that practically all of these exports are of Lake Superior ores, passing directly from the mines to Canadian furnaces. Smaller tonnages go into Canada from the Lake Champlain region. A tonnage reported by the Government as clearing each year from Puget Sound is somewhat mystifying, unless it is of ore sent as flux to some British Columbia smelter.

EXPORTS OF IRON ORE, 1899–1912

Year	Tonnage	Year	Tonnage
1899	40,665	1906	265,240
1900	51,460	1907	278,608
1901	64,703	1908	309,099
1902	88,455	1909	455,934
1903	80,611	1910	748,875
1904	213,865	1911	768,386
1905	208,017	1912	1,195,742

SOURCES OF UNITED STATES IRON ORE IMPORTS

Country	1909		1910		1911		1912	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Cuba	927,774	$2,681,028	1,451,096	$4,459,789	1,147,879	$3,218,485	1,398,593	$3,969,986
Spain	291,547	664,460	439,868	1,040,589	194,965	502,453	92,061	222,951
French Africa	37,208	67,515	15,471	36,791	4,443	13,068	....	....
Greece	19,080	21,782	39,060	71,951	13,200	18,888	....	....
Newfoundland	224,395	330,056	209,006	343,892	174,853	286,997	145,355	217,087
United Kingdom	869	12,846	11,388	52,591	1,436	19,725	10,229	20,587
Germany	3	100	3	58	2	76	1,729	5,602
Netherlands	....	....	....	....	223	420	5	72
Canada	27,155	84,613	95,005	251,086	50,480	106,038	106,675	201,882
Belgium	3	179	158	644	....	....	....	....
Russia	32,010	62,418	12,570	48,279	....	....	3,916	16,709
Sweden	120,564	627,315	259,911	1,391,976	219,238	1,215,588	333,863	1,781,579
Other countries	14,349	26,766	57,495	134,579	5,013	30,898	12,150	63,235
Total	1,694,957	$4,579,078	2,591,031	$7,832,225	1,811,732	5,412,636	2,104,576	$6,499,690

With the completion of the Ojibway plant of the United States Steel Corporation it is of course obvious that exports of American ore will increase largely.

Tonnage Available for Consumption.—In a later chapter some attempt will be made to arrive at an estimate of the actual consumption of ore in the United States, in comparison with the amount of pig iron produced. At present, however, it will be of more immediate interest to determine merely the amount of ore which is nominally available for consumption each year, by striking a balance between production, imports and exports. Thus I have done in the following table, which covers the years 1899 to 1912 inclusive.

TONNAGE AVAILABLE FOR CONSUMPTION, 1899-1912

Year	Domestic production	Imports	Exports	Available for consumption
1899	24,683,173	674,082	40,665	25,316,590
1900	27,553,161	897,831	51,460	28,399,512
1901	28,887,479	966,950	64,703	29,789,726
1902	35,554,135	1,165,470	88,445	36,631,160
1903	35,019,308	980,440	80,611	35,919,137
1904	27,644,330	487,613	213,865	27,918,078
1905	42,526,133	845,651	208,017	43,163,767
1906	47,749,728	1,060,390	265,240	48,544,878
1907	51,720,619	1,229,168	278,608	52,671,179
1908	35,924,771	776,898	309,089	36,392,580
1909	51,155,437	1,694,957	455,934	52,394,560
1910	56,889,734	2,591,031	748,875	58,731,890
1911	43,876,552	1,811,732	768,386	44,919,898
1912	55,150,147	2,104,576	1,195,742	56,058,981

American Ore Output, by States.—The following tables give the output of iron ore in the United States during the years 1910, 1911 and 1912 respectively, classified both by kinds of ore and by the States in which it was produced. As the data contained in these tables will be useful as bases for various investigations, they are inserted as a matter of convenient record.

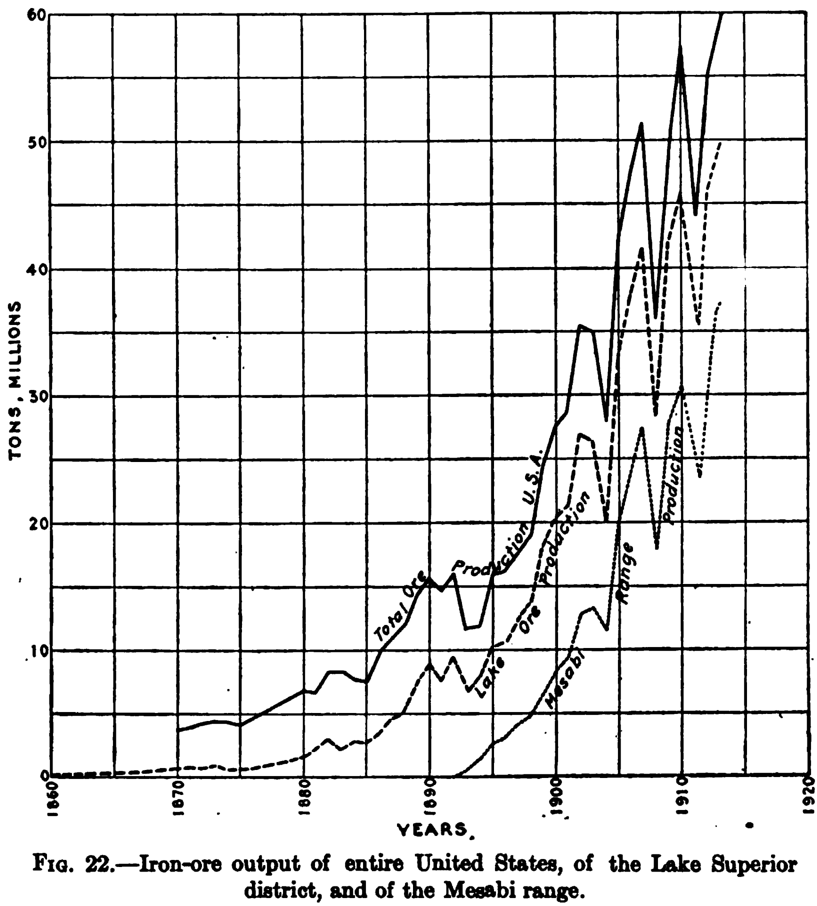


FIG. 22.—Iron-ore output of entire United States, of the Lake Superior district, and of the Mesabi range.

1910

State	Hematite	Brown ore	Magnetite	Carbonate	Total quantity
Alabama	3,678,139	1,123,136	....	......	4,801,275
California, Colorado, New Mexico, Washington, and Wyoming	656,629	15,975	189,246	......	861,850
Connecticut and Massachusetts	....	34,158	....	......	34,158
Georgia	60,324	253,554	....	......	313,878
Kentucky and West Virginia	47,493	16,854	....	......	64,347
Maryland	....	14,062	....	......	14,062
Michigan	13,303,906	....	....	......	13,303,906
Minnesota	31,966,769	....	....	......	31,966,769
Missouri	55,832	22,509	....	......	78,341
New Jersey	....	(a)	[a]521,832	......	521,832
New York	64,738	(a)	[a]1,222,471	......	1,287,209
North Carolina	....	....	65,278	......	65,278
Ohio	....	....	....	22,320	22,320
Pennsylvania	846	106,544	632,409	......	739,799
Tennessee	301,838	430,409	....	......	732,247
Texas	....	29,535	....	......	29,535
Virginia	81,647	821,131	599	......	903,377
Wisconsin	1,148,846	705	....	......	1,149,551
Total	51,367,007	2,868,572	2,631,835	22,320	56,889,734

[a] Brown ore is included in magnetite.

1911

State	Hematite	Brown ore	Magnetite	Carbonate	Total quantity
Alabama	2,983,440	844,351	....	....	3,827,791
Georgia	14,955	188,934	....	....	203,889
Michigan	10,329,039	....	....	....	10,329,039
Minnesota	24,645,105	....	....	....	24,645,105
Missouri	57,201	8,124	....	....	65,325
New Jersey	....	2,182	464,052	....	466,234
New York	32,048	....	1,029,231	....	1,061,279
Ohio	....	....	....	15,707	15,707
Pennsylvania	9,692	49,906	477,908	....	537,506
Tennessee	255,373	208,462	....	....	463,835
Utah	....	39,903	....	....	39,903
Virginia	63,019	550,142	862	....	614,023
Wisconsin	698,660	....	....	....	698,660
Other States[a]	537,692	140,090	230,474	....	908,256
Total	39,626,224	2,032,094	2,202,527	15,707	43,876,552

[a] California, Colorado, Connecticut, Idaho, Kentucky, Maryland, Massachusetts, Mississippi, Montana, Nevada, New Mexico, North Carolina, West Virginia, and Wyoming.

1912

State	Hematite	Brown ore	Magnetite	Carbon-ate	Total quantity	Percentage of increase (+) or decrease (−) in 1912
Alabama...	3,814,361	749,242	....	....	4,563,603	+19.22
California..	....	....	2,508	....	2,508	([a])
Georgia....	([b])	[b]134,637	....	....	134,637	−33.97
Kentucky..	27,373	....	....	....	27,373	([a])
Maryland..	....	3,200	....	....	3,200	([a])
Michigan..	11,191,430	....	....	....	11,191,430	+ 8.35
Minnesota.	34,431,768	....	....	....	34,431,768	+39.71
Missouri...	39,721	3,759	....	....	43,480	−33.44
New Jersey	....	....	364,673	....	364,673	−21.78
New York.	106,327	....	1,110,345	....	1,216,672	+14.64
North Carolina..	....	....	68,322	....	68,322	([a])
Ohio.......	....	....	....	10,346	10,346	−34.13
Pennsylvania.....	10,557	30,371	476,153	....	517,081	− 3.80
Tennessee..	245,754	171,131	....	....	416,885	−10.12
Texas......	....	3,000	....	....	3,000	([a])
Utah......	....	7,280	....	....	7,280	−81.76
Virginia....	47,472	398,833	....	....	446,305	−27.31
West Virginia....	....	5,061	....	....	5,061	([a])
Wisconsin..	860,600	....	....	....	860,600	+23.18
Other States[c]....	562,219	116,172	157,532	....	835,923	+[a]4.09
Total....	51,345,782	1,614,486	2,179,533	10,346	55,150,147	+25.69

[a] Less than three producers in California, Kentucky, Maryland, North Carolina, Texas, and West Virginia in 1911, and permission not secured to publish State totals. Increases and decreases in 1912, therefore, included in "Other States."

[b] Hematite included in brown ore.

[c] Colorado, Connecticut, Idaho, Massachusetts, Montana, Nevada, New Mexico, and Wyoming.

Iron-Ore Districts of the United States.—Iron ores, in greater or less quantity, are known to occur in almost every State and Territory of the United States; and at one time or another iron mining has been carried on in practically all of these political divisions. During recent years, however, from 25 to 30 states appear in the producing list, and no serious change in this respect seems likely to occur in the near future.

For convenience both in description and in the presentation

of statistics in a really intelligible form, it is advisable to group the producing states in four natural districts, defined both by geographic and trade conditions. The four districts in question, with the states which they include, are:

1. *Lake Superior District;* including the producing states of Minnesota, Michigan and Wisconsin.

2. *Southern District;* including the states of Alabama, Georgia, the Carolinas, the Virginias, Tennessee, Kentucky, Maryland, Arkansas, Missouri and Texas.

3. *Northeastern District;* including New York, New England, New Jersey, Pennsylvania and Ohio.

4. *Western District;* including the states of the Plains, the Rocky Mountain and Pacific Coast regions.

The following table gives the production of iron ore in these four districts during the years 1905 to 1912, inclusive.

IRON ORE PRODUCTION, BY DISTRICTS, 1905–1912

District	1905		1906		1907	
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Lake Superior..	33,480,367	78.73	38,035,084	79.66	41,638,744	80.51
Southern......	5,700,819	13.41	6,325,710	13.24	6,427,195	12.42
Northeastern...	2,520,845	5.93	2,582,666	5.41	2,823,422	5.46
Western.......	824,102	1.93	806,268	1.69	831,258	1.61
	42,526,133	100.00	47,749,728	100.00	51,720,619	100.00

District	1908		1909		1910	
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Lake Superior..	28,225 412	78.57	41,942,969	81.99	46,420,226	81.60
Southern......	5,639,201	15.70	6,294,145	12.30	7,002,340	12.31
Northeastern...	1,590,098	4.42	2,280,741	4.46	2,605,318	4.58
Western.......	470,060	1.31	637,582	1.25	861,850	1.51
	35,924,771	100.00	51,155,437	100.00	56,889,734	100.00

District	1911		1912		1913	
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Lake Superior..	35,672,804	81.30	46,483,798	84.29	....	......
Southern......	5,367,854	12.21	5,711,866	10.35	....	......
Northeastern...	2,098,923	4.79	2,139,058	3.88	....	......
Western.......	746,971	1.70	815,425	1.48	....	......
	43,876,552	100.00	55,150,147	100.00	....	......

Ore-consuming Districts.—The preceding data as to production, imports, exports etc., are rendered more intelligible when they are placed in relation to the actual ore-consuming areas or districts of the United States. Fortunately this can be done, if not with absolute precision, at least with sufficiently results to be of industrial value.

From the steel-making standpoint, there are four iron-ore consuming regions in the United States. These are as follows:

1. *The Central Region;* including all the furnaces in Michigan, Minnesota, Wisconsin, Missouri, Illinois, Indiana, Ohio, western Pennsylvania and western New York. These plants normally use Lake Superior ores (plus a little local ore in Ohio and Missouri).

2. *The North Atlantic Region;* including New England, New Jersey, eastern New York, eastern Pennsylvania and Maryland. These plants normally use local or imported ores; though some Lake ore comes in at times.

3. *The Southern Region;* including all plants from Missouri and Maryland south to the Gulf of Mexico. These plants all use local ores.

4. *The Western Region;* including plants in the Rocky Mountain and Pacific Coast states. These plants now use local ores entirely.

Using this classification as the basis, it is possible to allot the ore production, imports and exports among these four regions with a close approach to accuracy. I have prepared the following table, which gives the results of such allotment.

ORE CONSUMPTION IN VARIOUS REGIONS

	1910		1911		1912	
	Tons	Per-cent	Tons	Per-cent	Tons	Per-cent
Central Region....	45,790,000	78.0	34,943,000	77.7	45,360,000	81.0
North Atlantic....	9,466,000	16.0	7,156,000	15.9	7,765,000	13.8
Southern Region...	2,605,000	4.5	2,099,000	4.7	2,139,000	3.8
Western Region...	868,000	1.5	732,000	1.7	795,000	1.4
	58,729,000	100.0	44,930,000	100.0	56,059,000	100.0

It will be noted that the totals reached in this way do not agree exactly with those in a preceding table giving estimates of the tonnage available for consumption in the entire United

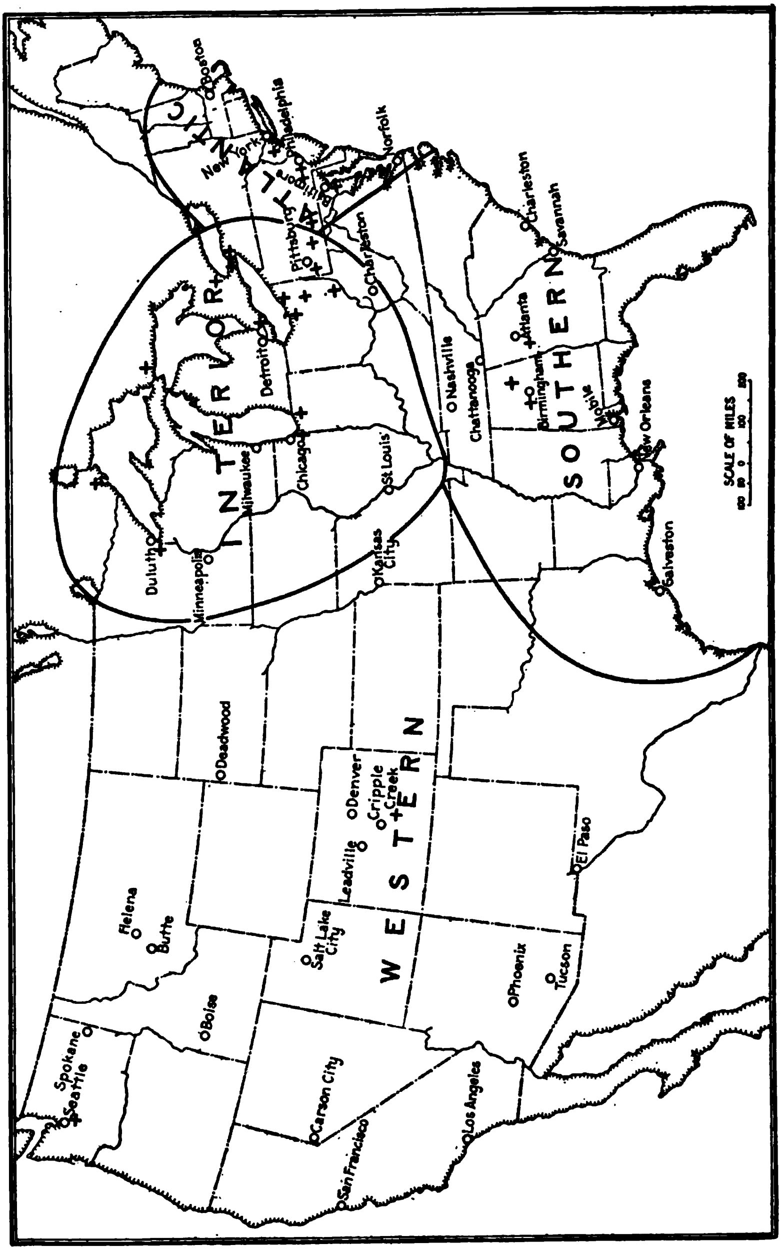


FIG. 23.—Ore-consuming districts of the United States.

States in different years. The differences are due to small tonnages which can not be precisely allotted without more information than is now available; and the possible errors are too small, in any event, to seriously affect the value of the results.

CHAPTER XVII

THE LAKE SUPERIOR DISTRICT

Considered either from the industrial or the geologic standpoint, the Lake Superior district includes portions of the three states which border on that lake, together with part of the Canadian Province of Ontario. In the present volume, however, such developments as have been made on the Canadian side of the boundary will be briefly noted in a later chapter, while in this chapter attention will be directed chiefly to that portion of the Lake district which lies in the United States.

During recent years the Lake Superior district has produced about four-fifths of the entire iron-ore output of the United States. There is no serious probability that this proportion will decrease much in the near future, so that for many years to come this region will be the most important source of our domestic-ore supply.

LOCATION AND GEOLOGY

The Lake Superior Ore Ranges.—A number of more or less distinct areas or "ranges" contribute to make up the total output of the Lake district. The progress of development tends to change the classification somewhat, but it can still be said that five ranges produce the bulk of the output. These are the Mesabi and Vermillion, located in Minnesota; the Marquette, entirely in Michigan; and the Gogebic and Menominee, mostly in Michigan but extending over into Wisconsin.

In addition to these five great ranges, relatively small shipments are now made from the Baraboo and Iron Ridge areas in southern Wisconsin, the Cuyuna range in Minnesota, and occasionally from Spring Valley and other brown-ore areas in northwestern Wisconsin. At intervals, it may be noted, small shipments have also been made from a brown-ore area in Iowa, which reached the same markets as the Lake ores, and is mentioned here merely to complete the record. The five ranges first

mentioned, with the Cuyuna and Baraboo, are closely alike geologically, producing hematite (with some magnetite) some pre-Cambrian rocks; the Iron Ridge area, however, is a district

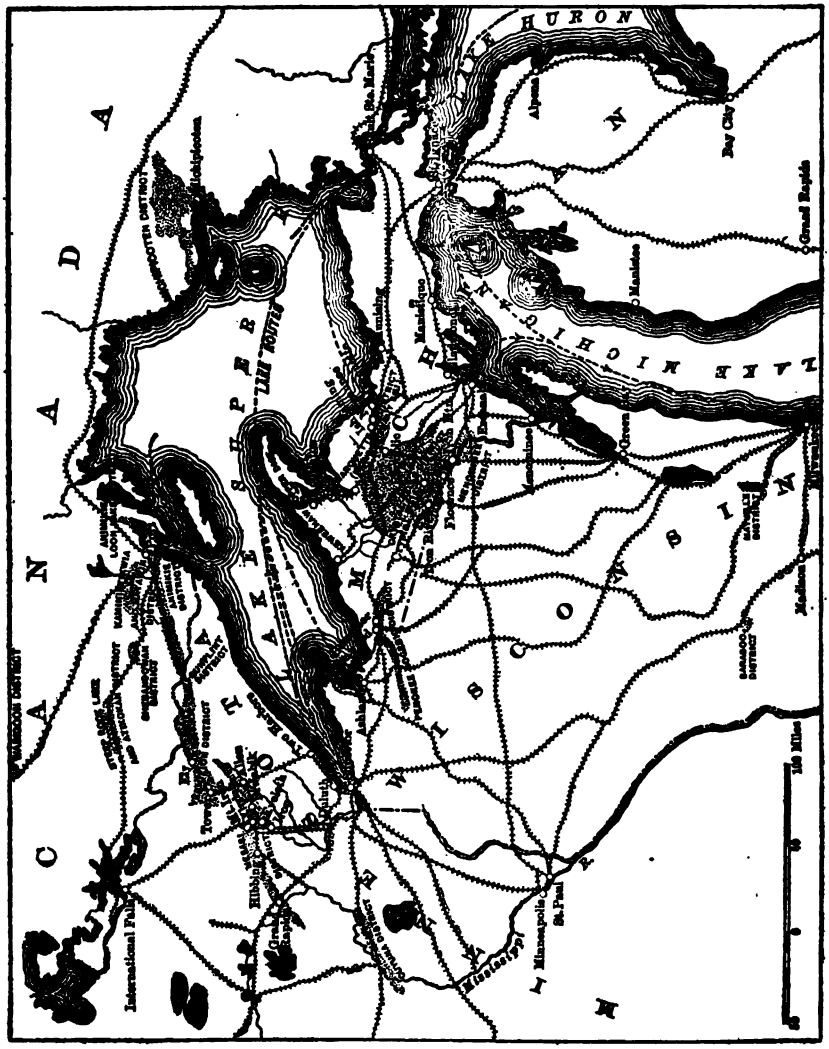


FIG. 24.—Map of the Lake Superior region showing ranges, ports, and routes. (Leith and Van Hise.)

producing Clinton ore like the red hematite of the Birmingham and other southern Appalachian regions.

The essential facts concerning the five principal ranges, to-

gether with less important areas in Canada or elsewhere in the Lake Superior district, are embodied in tabular form as follows:

LAKE SUPERIOR IRON-ORE RANGES

Range	Location	Opened	Production, opening in 1910, in long tons
Marquette..........	Michigan..................	1854	97,861,463
Menominee.........	Michigan and Wisconsin....	1872	76,390,887
Gogebic............	Michigan and Wisconsin....	1884	66,533,749
Vermillion..........	Minnesota.................	1884	30,708,055
Mesabi.............	Minnesota.................	1892	226,937,775
Michipicoten.......	Canada....................	1900	....
Baraboo............	Wisconsin.................	1903	....
Sudbury............	Canada....................	1906	....
Cuyuna............	Minnesota.................	1911	....

The grade of the Lake ores, as well as the shape, size and position of the ore deposits, are largely influenced by local geologic and topographic conditions on the different ranges. Flat-lying rocks, as on the Mesabi, give shallow deposits of soft ore, often workable as open cuts by the steam shovel. Steeply inclined rocks, as on the Michigan ranges, especially where later igneous action has also been a factor, give underground mines in harder ore. The ores now shipped from the Lake region average about 50 to 52 percent metallic iron in their natural or shipping condition.

General Geology of the Lake Region.—The Lake Superior iron region is, so far as the mining geology of its principal ranges is concerned, a district made up of igneous and metamorphic rocks. All of these are of pre-Cambrian age; and the major subdivisions are as follows, the youngest or newest series being at the top of the column.

PRINCIPAL GEOLOGIC DIVISIONS IN LAKE REGION

System	Series	Group
Algonkian.........	Keweenawan.......	Upper Keweenawan.
		Middle Keweenawan.
		Lower Keweenawan.
	Huronian..........	Upper Huronian or Animikie.
		Middle Huronian.
		Lower Huronian.
Archaean.........	Laurentian.........	Not subdivided.
	Keewatin..........	Not subdivided.

These groups are essentially recognizable throughout the district, though an apparently unnecessary complexity has been introduced by using different local names for them as developed in the different iron ranges. These local sub-divisions are summarized from data by Van Hise and Leith on pages 198 and 199.

Of the groups above named, three contain iron-bearing formations. These three, in the order of their productive importance are the Upper Huronian, the Middle Huronian and the Keewatin. Of these the Upper Huronian produces all of the ores of the Mesabi, Gogebic and Cuyuna ranges, and by far the bulk of the ores from the Menominee range. The Middle Huronian produces the bulk of the Marquette ores, all of the Baraboo output, and a small fraction of the Menominee ores. The Keewatin produces all of the Vermillion ores, as well as those of the Michipicoten, Atitokan and other Ontario districts.

Origin of the Ores.—The following statement as to the origin of the Lake Superior iron ores is summarized from the detailed reports by Van Hise and others, referred to elsewhere.

The iron-bearing formations, which now carry the Lake ores, are supposed to have been originally of sedimentary origin, though not exactly of the usual sedimentary type. They were made

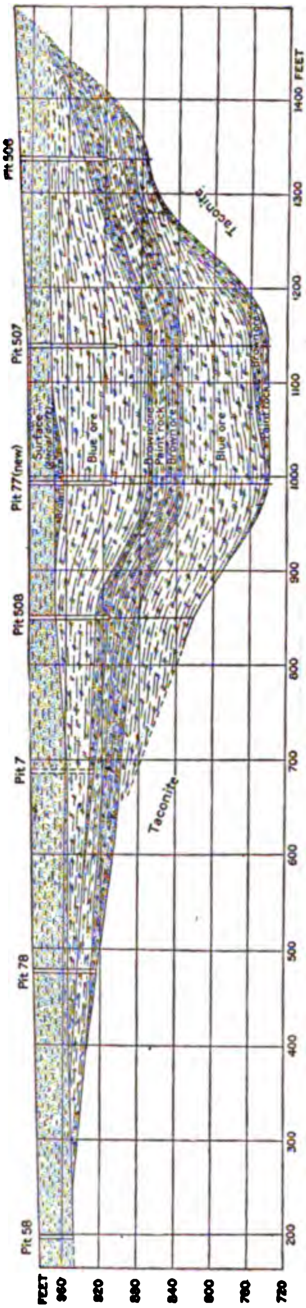


FIG. 25.—Section across a Mesabi ore-body. (Leith and Van Hise.)

CORRELATION OF PRE-CAMBRIAN ROCKS

System		Series and group	Marquette district	Menominee district	Iron River district
Algonkian	Keweenawan series	Upper	Not identified, but probably represented by part of intrusives in upper Huronian.	Granite (?)	
		Middle			
		Lower			
	Huronian series	Upper Huronian (Animikie group)	Greenstone intrusives and extrusives. Michigamme slate. To the south partly replaced by the volcanic upper-middle Huronian Clarksburg formation. Bijiki schist (iron bearing). Goodrich quartzite.	Quinnesec and other schists, greenstone intrusives and extrusives. Michigamme ("Hanbury") slate. Vulcan formation, subdivided into the Curry iron-bearing member, Brier slate member, and Traders iron-bearing member.	Greenstone intrusives and extrusives. Michigamme slate, including Vulcan iron-bearing member.
			— Unconformity —	— Unconformity —	
		Middle Huronian	Negaunee formation (chief productive iron-bearing formation). Siamo slate. Ajibik quartzite.	Quartzite; in most of district not separated from upper part of Randville dolomite.	Not identified.
			— Unconformity —	— Unconformity —	– Unconformity? –
		Lower Huronian	Wewe slate. Kona dolomite. Mesnard quartzite.	Randville dolomite. Sturgeon quartzite.	Saunders formation (interbedded dolomite and quartzite; believed to be the equivalent of the Randville dolomite and Sturgeon quartzite).
			— Unconformity —	— Unconformity —	—Unconformity—
Archean	Laurentian series (intrusive into Keewatin).		Granite, syenite, peridotite. Palmer gneiss.	Granites and gneisses cut by granite and diabase dikes.	
	Keewatin series		Kitchschist and Mona schist, the latter banded and in a few places containing narrow bands of non-productive iron-bearing formation.	Green schists.	Greenstone, green schists, and tuffs.

OF THE LAKE SUPERIOR REGION

Baraboo district	Mesabi district	Animikie or Loon Lake district	Cuyuna district	Vermillion district	Michipicoten district
	Absent.	Absent.	Absent.	Absent.	
	Embarrass granite (intrusive). Diabase. Duluth gabbro.	Conglomerate, sandstone, marl, and diabase sills (Logan sills).	Basic and acidic intrusive and extrusive rocks (Keweenawan?).	Duluth gabbro and diabase sills (Logan sills).	
	Unconformity	Unconformity		Unconformity	
Quartzite (upper Huronian?).	Acidic and basic intrusive rocks. Virginia slate. Biwabik formation (iron bearing and productive). Pokegama quartzite.	Black slate. Iron-bearing formation.	Virginia "St. Louis" slate, including Deerwood iron-bearing member.	Rove slate. Gunflint formation (iron bearing, but non-productive).	Absent.
Unconformity	Unconformity	Unconformity		Unconformity	
Granite, intrusive into lower formations. Freedom dolomite, mainly dolomite, including iron-bearing member in its lower horizon. Seeley slate. Baraboo quartzite.	Giants Range granite, intrusive into rocks below. Sediments (slate, graywacke, and conglomerate) which are the equivalent of the Knife Lake slate and Ogishke conglomerate of the Vermillion district.	Granite and greenstone, intrusive into rocks below. Slate, graywacke and conglomerate.		Granites, granite porphyries, dolerites, lamprophyres, intrusive into rocks below. Knife Lake slate. Agawa formation (iron bearing, but non-productive). Ogishke conglomerate.	Lower-middle Huronian ("Upper Huronian" of Coleman and Willmott): Granite and greenstone, intrusive into rocks below. Doré conglomerate.
Absent					
Unconformity	Unconformity	Unconformity		Unconformity?	Unconformity
Granites, rhyolites, tuffs, etc. (Laurentian?).	Granites and porphyries.	Granites and gneisses, intrusive into Keewatin.		Granites and other intrusive rocks.	Granites and gneisses.
	Greenstones, hornblende schists, and porphyries.	Green schists, greenstones, and mashed porphyries.		Soudan formation (iron bearing and productive). Ely greenstone an ellipsoidally parted basic igneous and largely volcanic rock.	("Lower Huronian" of Coleman and Willmott): Eleanor slate. Helen formation (iron bearing and productive). Wawa tuff. Gros Cap greenstone.

chiefly of beds of iron carbonate and iron silicate, both of which up were chemical deposits in marine basins. In their original form, these beds therefore differed from the iron deposits of the present day chiefly in the facts that (a) their iron was present in the ferrous form, while the ores are ferric oxides; (b) silica and carbon dioxide were present in the original beds, while in the existing ores carbon dioxide is absent and silica relatively low. It is obvious that the present ores could be produced from the original carbonates and silicates by simple removal of carbon dioxide and silica, which would result in a *relative* increase in the iron.

The accepted theory as to the manner in which this change was effected may be summarized as follows:

After their deposition the original iron-bearing beds were

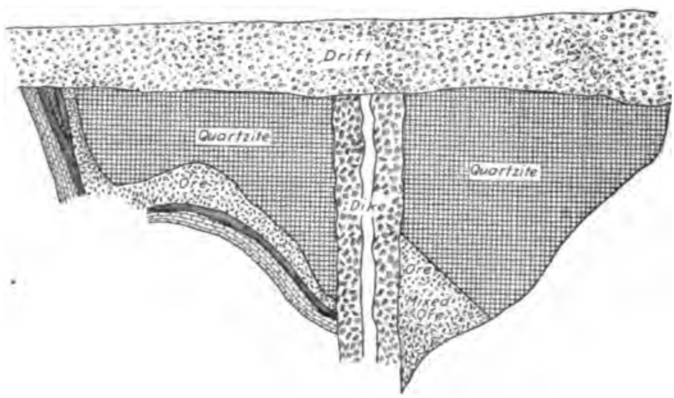


FIG. 26.—Cross-section of typical ore deposit in the Marquette district, Michigan (U. S. G. S.).

metamorphosed and folded. During and after these changes, percolating waters passing downward from the surface produced changes in the chemical and physical character of the original beds. These changes involved decomposition of the original carbonate and siderite, the alteration of their iron to the ferric form, and the removal of carbon dioxide and silica. All of these, except the last, could be accomplished even by pure water, given sufficient time and freedom of access; but the removal of silica implies that the waters which effected it must have been alkaline in character. As the rocks of the region include both sediments and igneous rocks which could have given the water this characteristic, this offers no obstacle to the theory stated.

On some of the ranges, notably the Marquette and Vermillion, igneous action which took place after the ore deposits had been formed (as above outlined) has effected changes in the character of the ores, producing magnetities as distinct from the hematite which is the normal form in the other ranges.

The grade of the ores, and the shape, size and position of the ore deposits are influenced by local conditions on the different ranges. Flat-lying rocks, as on the Mesabi, give shallow deposits of soft ore, workable by the shovel. Steeply inclined rocks, as on the older ranges, give underground mines, in steeply dipping ore-bodies often of quite irregular form. These facts are well shown in figures 8, 9, 10, 25, 26 and 27, taken

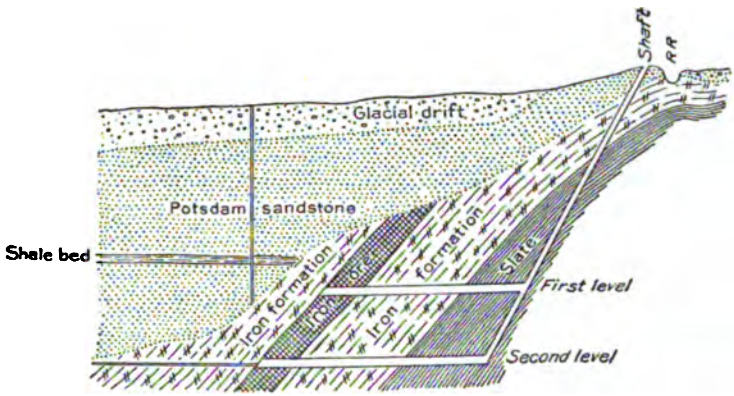


FIG. 27.—Cross-section of Illinois mine, Baraboo range, Wisconsin. (Weidman.)

from various reports by Van Hise, Leith and others, which give cross-sections of typical ore deposits on various ranges.

Mining and Concentration of Lake Ores.—On almost all of the Lake ranges mining was originally started in open cuts along the outcrop of prominent ore-bodies. On the Mesabi range, where the ore-bodies are flat-lying and relatively shallow, open-cut mining can be carried on economically in many cases, and about two-thirds of the Mesabi output comes from open-cut mines. The ore-bodies on the other ranges dip at steep angles, so that the cover soon becomes too heavy for anything except underground mining.

Until recently all of the Lake Superior ores were shipped and

used as mined, without any concentration or other treatment; and the greater portion of the output is still marketed in its natural condition. The growing scarcity of high-grade ores, however, has led to attempts to improve grade by treatment, and developments along two distinct lines are now in progress. The sandy ores of the western portion of the Mesabi range are now being washed to raise their iron grade and reduce silica; while some of the Canadian ores are roasted to lower their high sulphur content. Drying has been introduced at a few mines very recently.

As the average grade of the district falls, concentration will become more and more a necessity. If there were no competitive ores in sight, it would of course always be possible to ship Lake ores to Pittsburgh furnaces, and the result of lowered grade would simply be an increase in the cost of making pig iron. But as it is, there are abundant supplies of ore in Texas, Cuba and elsewhere which will become available in Pittsburgh as soon as the average Lake grade falls a little lower than its present level. Under these circumstances, it will be necessary, if these eastern markets are still to be held by Lake ores, to keep the shipping grade up to a point which will place them on at least a competitive basis as regards other ores.

Composition and Grade of Lake Ores.—In attempting to summarize briefly the chief facts concerning the mineral character, composition and grade of Lake Superior ores, the difficulty does not arise from lack of data, but from their abundance. Fortunately Van Hise and Leith, in a recent publication, have furnished a series of averages which are of great value in the present connection.

Practically all of the ore now shipped from the Lake Superior ranges is hematite, a very small percentage of the total output being magnetite, which comes from certain mines on the Marquette range. But it must be noted that the hematite is, to a very large extent, more or less hydrated, and that in places it carries sufficient combined water to be properly called a brown ore.

The following data on the average composition of the total shipments of Lake Superior iron ores for the year 1909, with the range in various constituents, are quoted from Monograph LII, U. S. Geological Survey.

The ores as shipped contained moisture ranging from 0.50 percent to 17.40 percent, the average moisture for the total shipments being 11.28 percent. After drying at 212° F., the total shipments gave on analysis the following average and range:

Constituent	Minimum	Average	Maximum
Metallic iron	35.74 percent	58.45 percent	65.34 percent
Manganese	0.00	0.71	7.20
Silica	2.50	7.67	40.77
Alumina	0.16	2.23	5.67
Lime	0.00	0.54	4.96
Magnesia	0.00	0.55	3.98
Sulphur	0.003	0.06	1.87
Phosphorus	0.008	0.091	1.28
Loss on ignition	0.00	4.12	10.00

In order that the general differences between the ores of the various ranges may be brought out, the averages for 1909 shipments, by ranges, are taken from the same publication and assembled in the table following:

Constituent	Mesabi	Vermillion	Gogebic	Marquette		Menominee			
				Marquette	Swansy	Crystal Falls	Iron River	Florence	Menominee
Moisture (loss at 212° F.)	12.27[a]	5.06	11.30	9.52	13.50	8.42	8.34	9.76	6.67
Average analyses of ores dried at 212° F.									
Metallic iron	58.83	63.79	59.62	57.05	58.60	54.79	54.35	54.70	52.13
Manganese	0.82	0.11	0.77	n. d.	0.71	0.80	0.30	0.08	0.19
Silica	6.80	4.90	8.16	10.16	10.20	7.71	8.77	6.89	16.77
Alumina	2.23	2.93	1.92	2.18	1.05	2.50	3.07	4.17	1.41
Lime	0.32	0.23	0.37	n. d.	1.15	2.63	1.34	1.80	1.31
Magnesia	0.32	0.05	0.28	n. d.	0.46	2.16	1.49	2.86	2.70
Sulphur	0.069	....	0.034	n. d.	0.012	0.071	0.056	0.173	0.012
Phosphorus	0.062	0.052	0.060	0.105	0.211	0.495	0.404	0.319	0.074
Loss on ignition	4.72	0.85	2.82	2.31	.25	4.11	5.74	5.20	2.52

In both of the preceding tables, the analyses are quoted on a dry basis; but since in each case the moisture lost at or below 212° F. is also given, it is possible to calculate from these data the natural or shipping grade of the ores.

Changes in Average Ore Grades.—For comparative industrial purposes, however, we have available a still more valuable series of data, prepared by the Secretary of the Lake Superior Iron Ore

Association. These statistics, the more general portions of which are summarized in the tables following, cover the average grades of ore from each of the ranges, over a series of years.

Taking first the matter of iron content the following results are shown, all iron being stated on a natural basis.

AVERAGE IRON GRADE OF LAKE ORES, 1902–1912

Year	Mesabi range	Old ranges	All ranges
1902	56.07 percent	56.40	56.22
1903	55.19	55.92	55.50
1904	55.45	55.76	55.58
1905	54.24	55.19	54.61
1906	53.44	54.63	53.87
1907	53.11	54.01	53.40
1908	52.66	53.63	52.96
1909	51.49	53.49	52.11
1910	51.42	53.52	52.07
1911	51.18	53.62	51.89
1912	51.20	53.71	51.96
1913	.....	.....	.....
1914	.. ..	.....	.....
1915	.....	.....	.....

The fairly steady decrease in grade from both the Mesabi and the older ranges, from 1902 until a few years ago, is very noticeable. During the past few years this fall in grade has stopped, momentarily at least.

Further facts of interest, relating to the phosphorus content of the Lake ores, are brought out by the following table.

CHANGES IN PHOSPHORUS CONTENT, 1902–1912

Year	Phosphorus content of Bessemer ores			Percentage, Bessemer, total tonnage		
	Mesabi	Old ranges	All ranges	Mesabi	Old ranges	All ranges
1902	0.03948	0.04097	0.03995	80.6	47.4	64.9
1903	0.04044	0.04043	0.04043	74.9	49.9	63.7
1904	0.04010	0.04035	0.04018	79.9	47.3	65.1
1905	0.04215	0.04106	0.04183	70.1	46.3	60.9
1906	0.04408	0.04204	0.04354	69.0	44.4	60.2
1907	0.04558	0.04060	0.04437	63.2	42.1	56.4
1908	0.04459	0.04174	0.04387	57.2	43.6	53.0
1909	0.04528	0.04226	0.04446	48.0	38.8	45.1
1910	0.04608	0.04132	0.04472	46.3	41.5	44.8
1911	0.04620	0.03881	0.04438	49.3	39.9	46.6
1912	0.04685	0.04000	0.04504	45.3	37.2	41.9
1913	....	....	....	....	....	....
1914	....	....	....	....	....	....
1915	....	....	....	....	....	....

Along with the decrease in iron content, therefore, the phosphorus content of the Mesabi Bessemer ores has increased quite noticeably. What is still more striking, however, is the change in steel-making processes indicated by the last three columns of the preceding table, which show the rise in the percentage of non-Bessemer ores brought down each year.

Transportation and Markets.—The Lake ores now supply all the furnaces in Michigan, Wisconsin, Minnesota, Illinois and Indiana, as well as those in western New York, western Pennsylvania and northern Ohio. A line drawn from Buffalo through Johnstown to Ironton and then northwest to Chicago will be about the eastern and southern boundary of the strictly Lake market. Outside of this, however, is a zone where Lake ores are sold and used in competition with local or imported ores. In this zone, conditions in the ore and metal markets determine to what extent, in any given year, Lake ores can be used. The extreme limits of shipment in this direction are, it is believed, St. Louis, Lowmoor (Va.), and Bethlehem, Pa.; and these are not to be regarded as normal Lake markets. But, even setting aside all of the competitive zone, the area in which the Lake ores furnish the total supply concludes the bulk of the steel plants of the country, and over 85 percent of our present steel output comes from Lake ores.

In order to reach these markets, the ores from the Lake ranges have to face a serious transportation problem. A relatively small portion of the total tonnage travels to its destination by all-rail routes, but by far the greater portion goes by rail to a harbor on Lake Superior or Lake Michigan; and is taken by ore-carrying boats either down Lake Michigan to Chicago or Gary, or through Lake Huron to ports on the lower lakes. For most of the tonnage, even these lower lake ports are not ultimate destinations, but a further rail haul is required to place the ore at the furnaces. The total distances involved, rail and water, range from some three hundred miles for ores from the Menominee range to Chicago, up to over one thousand miles for ores from the Vermillion and Mesabi ranges to Pittsburgh or Buffalo.

It will be of interest to take up this question on a quantitative basis, so as to get some idea of the relative tonnages which take the different routes, and of the relative costs at which they are handled. In order to clear the ground, we may first of all dis-

pose of the all-rail tonnage. This normally amounts to one million tons or less, and is distributed chiefly to furnaces in the Lake Superior states, though occasional shipments are made all-rail to more distant points. The relative importance of this tonnage may be seen by considering that total shipments from the Lake ranges in 1910 amounted to 43,442,397 tons, of which only 813,639 tons traveled all-rail to their destination. The

Fig. 28.—Map of market area for Lake Superior ores.

remaining 42,628,758 tons used one of the combined rail and water routes.

The first link in the combined routes is in every case a rail haul from the mines to a harbor on Lake Superior or Lake Michigan. The routes available from the different ranges, the harbors usually shipped from, and the present rates from mine to harbor are shown in the following table:

Range	Railroad to harbor	Harbor	Rate per ton, mine to harbor	Average haul, miles
Vermillion.	Duluth and Iron Range.	Two Harbors, Minn.	0.60	70–90
Mesabi.	Duluth and Iron Range.	Two Harbors, Minn.	0.60	65
Mesabi.	Duluth, Missabe and Northern.	Duluth, Minn.	0.60	80
Mesabi,	Great Northern.	Superior, Wis.	0.60	120
Gogebic.	Wisconsin Central.	Ashland, Wis.	0.40	50
Gogebic.	Chicago & Northwestern.	Ashland, Wis.	0.40	40
Menominee.	Chicago, Milwaukee & St. Paul.	Escanaba, Mich.	0.40	40–60
Menominee.	Chicago & Northwestern.	Escanaba, Mich.	0.40	45–83
Marquette.	Lake Superior & Ishpeming.	Marquette, Mich.	0.25	12–36
Marquette.	Chicago & Northwestern.	Escanaba, Mich.	0.40	45–70
Marquette.	Duluth, South Shore & Atlantic.	Marquette, Mich.	0.25	12–35

Of the railroads above mentioned as handling ore traffic between the mines and the harbors, three are owned by iron companies, while the others are parts of the Great Northern, Canadian Pacific, St. Paul and Chicago Northwestern systems. The three roads controlled by iron companies are the Lake Superior and Ishpeming, controlled by the Cleveland-Cliffs Company; and the Duluth & Iron Range, and Duluth Missabe & Northern, controlled by the Oliver Iron Mining Company. Owing to the close connection of the Great Northern Railway, in ownership and management, with heavy ore-land holdings, it might also be considered in this class.

From the harbors down the Lakes the ore is handled in freighters designed specially for this traffic. Part of the shipping employed in this work is owned or controlled by iron companies; part is entirely independent. The rates vary from season to season, but the usual range of late years, from various upper lake harbors to ports on the lower lakes has been between sixty and seventy-five cents per ton, the average freight on all ore tonnage handled during the past five years being close to the higher figure named. The following tables, quoted from the Iron Trade Review, give data bearing on the relative amounts of the tonnage handled at various points of shipment and receipt during recent years. Receipts at Chicago and Gary account for practically all of the difference between the two sets of figures.

SHIPMENTS OF LAKE SUPERIOR IRON ORE, 1907–1912

Shipping port	1907	1908	1909	1910	1911	1912
Escanaba, Mich....	5,761,988	3,351,502	5,747,801	4,959,726	4,278,445	5,234,655
Marquette, Mich..	3,013,826	1,487,487	2,909,451	3,248,516	2,200,380	3,296,761
Ashland, Wis......	3,436,867	2,513,670	3,834,207	4,094,374	2,429,290	4,797,101
Two Harbors, Minn...........	8,188,906	5,702,237	9,181,132	8,271,177	6,367,537	9,370,969
Superior, Wis......	7,440,386	3,564,030	6,540,505	8,414,799	9,920,490	14,240,714
Duluth, Minn....	13,448,736	8,808,168	13,470,503	13,640,166	6,934,269	10,495,577
Total by Lake..	41,290,709	25,427,094	41,683,599	42,628,758	32,130,411	47,435,777
Total by rail......	975,959	587,893	903,270	813,639	662,719	785,769
Total..........	42,266,668	26,014,987	42,586,869	43,442,397	32,793,130	48,221,546

IRON-ORE RECEIPTS AT LAKE MICHIGAN PORTS, 1909–1912

Port	1909	1910	1911	1912
Elk Rapids, Mich.........	46,037	60,857	26,814	47,947
East Jordan, Mich........	18,623	37,910	36,232	42,878
Milwaukee, Wis..........	178,720	121,446	109,255	138,065
Gary, Ind...............	1,921,813	1,775,880	1,302,745	2,088,327
Indiana Harbor, Ind......	....	287,172	365,312	514,748
South Chicago, Ill........	4,673,818	5,080,679	3,685,100	5,480,105
Boyne City, Mich........	37,062	50,355	33,000	45,000
Fruitport, Mich..........	53,761	37,785	....	....
Total.................	6,929,831	7,452,084	5,558,458	8,357,070

IRON-ORE RECEIPTS AT LAKE ERIE PORTS, 1907–1912

Port	1907	1908	1909	1910	1911	1912
Toledo..........	1,314,140	680,553	1,374,224	1,225,202	493,345	1,405,023
Sandusky........	83,043	....	11,088	....	....	....
Huron...........	971,430	213,377	243,082	197,951	223,947	540,586
Lorain...........	2,621,025	2,286,388	2,796,856	2,884,738	2,937,605	3,771,350
Cleveland........	6,495,998	4,240,816	6,051,342	6,344,943	4,584,211	7,914,836
Fairport.........	2,437,649	1,518,961	1,734,277	1,516,434	666,365	1,810,381
Ashtabula........	7,521,859	3,012,064	8,056,941	9,620,638	6,359,131	8,158,080
Conneaut........	5,875,937	4,798,631	7,007,834	6,309,548	6,931,278	7,839,831
Erie.............	2,294,239	828,602	1,235,057	942,592	289,400	547,067
Buffalo..........	5,580,438	2,835,099	5,002,235	4,704,439	2,802,976	5,060,642
Detroit..........	153,157	112,561	159,889	296,412	243,292	418,057
Total..........	35,348,915	20,527,052	33,672,825	34,042,897	25,531,550	37,465,853

Of the ore which reaches ports on Lake Erie, during the seven months which comprise the navigation season of an ordinary year, a certain portion is used, as at Lorain, Cleveland and Buffalo in strictly local furnaces. But the greater portion of the tonnage received is passed on by rail to more distant furnaces at Youngs-

town, Pittsburgh and elsewhere. Heavy stocks of ore are held at the lower lake ports at the close of navigation, and though these are drawn down, of course, during the winter and early spring, the stocks still on hand at the opening of navigation are still very large. On December 1, 1912, for example, the Iron Trade Review reports stocks held at Lower Lake ports as being 9,497,168 tons; while on May 1, 1913, the stocks still on hand then amounted to 5,706,477 tons.

History and Statistics.—The first discovery of iron ore in the Lake Superior district was made in 1844, on what is now the Marquette range, by a government surveying party. Within a year attempts to smelt the ore locally were under way, while as early as 1850 small test shipments were made to a Pennsylvania furnace. Development was retarded, however, by the lack of transportation facilities. These were improved by the opening, in 1855 of a ship canal at the Sault, and in 1857 of a railroad from the mines to Lake Superior. It is interesting to note that Henry Clay ridiculed the Sault canal project, just as at a later date another Kentucky senator immortalized himself by an asinine speech regarding the future of Duluth.

For thirty years the Marquette range furnished all the Lake ore, reaching shipments of about one million tons a year in the decade beginning in 1870. The second of the ranges to be opened was the Menominee, first shipping in 1887; followed by the Gogebic and Vermillion in 1884. The four ranges so far named are often called the Old Ranges, in distinction from the Mesabi, which did not commence shipping until 1892. This last of the important ranges was, however, the greatest of all; and within four years of its opening had become the leading range in point of annual output, a position it has since retained.

Within the past decade two far less important ranges—the Baraboo and Cuyuna—have been developed to the shipping point.

The following table reprinted from the annual official volume on Mineral Resources of the United States for 1912, shows the total production of the Lake Superior district by ranges. The figures prior to 1872 were collected by A. P. Swineford, editor Marquette Mining Journal; those for 1872 to 1877, inclusive, are from the Michigan Mineral Statistics; those from 1878 to 1888, inclusive, were collected by W. J. Stevens; and the later figures were collected by the United States Geological Survey.

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PRODUCTION OF LAKE SUPERIOR IRON ORE, 1854–1912, BY RANGES, IN LONG TONS

Year	Marquette	Menominee	Gogebic	Vermillion	Mesabi	Cuyuna	Total
1854–1869	3,112,209	....	....	....	....	....	3,112,209
1870	859,507	....	....	....	....	....	859,507
1871	813,984	....	....	....	....	....	813,984
1872	948,553	....	....	....	....	....	948,553
1873	1,195,234	....	....	....	....	....	1,195,234
1874	899,934	....	....	....	....	....	899,934
1875	881,166	....	....	....	....	....	881,166
1876	993,311	....	....	....	....	....	993,311
1877	1,014,754	10,375	....	....	....	....	1,025,129
1878	1,033,082	78,028	....	....	....	....	1,111,110
1879	1,130,019	245,672	....	....	....	....	1,375,691
1880	1,384,010	524,735	....	....	....	....	1,908,745
1881	1,579,834	726,671	....	....	....	....	2,306,505
1882	1,829,394	1,136,018	....	....	....	....	2,965,412
1883	1,305,364	1,047,863	....	....	....	....	2,353.227
1884	1,559,912	895,634	1,022	62,122	....	....	2,518,690
1885	1,430,862	690,435	119,590	227,075	....	....	2,467,962
1886	1,627,383	880,006	756,237	307,948	....	....	3,571,574
1887	1,851,717	1,199,343	1,285,265	394,910	....	....	4,731,235
1888	1,918,672	1,191,097	1,433,689	511,953	....	....	5,055,411
1889	2,631,026	1,876,157	2,147,923	864,508	....	....	7,519,614
1890	2,863,848	2,274,192	2,914,081	891,910	....	....	8,944,031
1891	2,778,482	1,856,124	2,041,754	945,105	....	....	7,621,465
1892	2,848,552	2,402,195	3,058,176	1,226,220	29,245	....	9,564,388
1893	2,064,827	1,563,049	1,466,815	815,735	684,194	....	6,594,620
1894	1,935,379	1,255,255	1,523,451	1,055,229	1,913,234	....	7,682,548
1895	1,982,080	1,794,970	2,625,475	1,027,103	2,839,350	....	10,268,978
1896	2,418,846	1,763,235	2,100,398	1,200,907	3,082,973	....	10,566,359
1897	2,673,785	1,767,220	2,163,088	1,381,278	4,220,151	....	12,205,522
1898	2,987,930	2,275,664	2,552,205	1,125,538	4,837,971	....	13,779,308
1899	3,634,596	3,281,422	2,725,648	1,643,984	6,517,305	....	17,802,955
1900	3,945,068	3,680,738	3,104,033	1,675,949	8,158,450	....	20,564,238
1901	3,597,089	3,697,408	3,041,869	1,805,996	9,303,541	....	21,445,903
1902	3,734,712	4,421,250	3,683,792	2,057,532	13,080,118	....	26,977,404
1903	3,686,214	4,093,320	3,422,341	1,918,584	13,452,812	....	26,573,271
1904	2,465,448	2,871,130	2,132,898	1,056,430	11,672,405	....	20,198,311
1905	3,772,645	4,472,630	3,344,551	1,578,626	20,156,566	....	33,325,018
1906	4,070,914	4,962,357	3,484,023	1,794,186	23,564,891	....	37,876,371
1907	4,167,810	4,779,592	3,609,519	1,724,217	27,245,411	....	41,526,579
1908	3,309,917	2,904,011	3,241,931	927,206	17,725,014	....	28,108,079
1909	4,291,967	4,789,362	3,807,157	1,097,444	27,877,705	....	41,863,635
1910	4,631,427	4,983,729	4,746,818	1,390,360	30,576,409	....	46,328,743
1911	3,743,145	4,062,778	3,099,197	1,336,938	23,126,943	181,224	35,550,225
1912	3,545,012	4,465,466	3,926,632	1,457,273	32,604,756	369,739	46,368,878
Total.	105,149,620	84,919,131	73,559,578	33,502,266	282,669,474	550,963	580,351,032

The following table shows the total quantity of iron ore shipped from the Lake Superior district since 1854, the date of the opening of the Marquette range, the oldest of the Lake Superior ranges. This table gives the shipments as collected by

the Iron Trade Review and is inserted for comparison with the table giving the total production of the Lake Superior district, without regard to shipments:

SHIPMENTS OF LAKE SUPERIOR ORES, 1854–1912, IN LONG TONS

Year	Quantity	Year	Quantity	Year	Quantity
1854	3,000	1874	919,557	1894	7,748,932
1855	1,449	1875	891,257	1895	10,429,037
1856	36,343	1876	992,764	1896	9,934,828
1857	25,646	1877	1,015,087	1897	12,469,638
1858	15,876	1878	1,111,110	1898	14,024,673
1859	68,832	1879	1,375,691	1899	18,251,804
1860	114,401	1880	1,908,745	1900	19,059,393
1861	49,909	1881	2,306,505	1901	20,589,237
1862	124,169	1882	2,965,412	1902	27,571,121
1863	203,055	1883	2,353,288	1903	24,289,878
1864	243,127	1884	2,518,692	1904	21,822,839
1865	236,208	1885	2,466,372	1905	34,384,116
1866	278,796	1886	3,568,022	1906	38,565,762
1867	473,567	1887	4,730,577	1907	42,266,668
1868	491,449	1888	5,063,693	1908	26,014,987
1869	617,444	1889	7,292,754	1909	42,586,869
1870	830,940	1890	9,012,379	1910	43,442,397
1871	779,607	1891	7,062,233	1911	32,793,130
1872	900,901	1892	9,069,556	1912	48,221,546
1873	1,162,458	1893	6,060,492		
				Total	573,808,218

Ore Production by Ranges.—During 1912 the Mesabi range produced over two-thirds of the entire Lake Superior output, a proportion which has been approximately maintained since 1905. The Mesabi output of 1912, it may be noted, accounted for considerably over half the total American production. The other ranges may appear small compared to this, but some idea of their importance can be gained if we note that both the Menominee and Gogebic produced more ore in 1912 than the state of Alabama; and that even the Vermillion surpassed New York.

Publications on the Lake Superior District.—At different times during the past thirty years, various portions of the Lake Superior district have been examined and reported on in more or less detail by six official Geological Surveys, maintained respectively by the United States and Canadian governments, and Michigan,

Wisconsin, Minnesota and Ontario. In addition, several of the mining companies, notably the Oliver and Cleveland-Cliffs, have maintained geologic surveys. These private organizations, being placed in the field chiefly to secure actual results, have left little published records of their work. The official surveys, however, not being limited as to space or time, have published largely, several hundred reports and papers being listed; and since the various organizations managed to differ on many important points, the literature of Lake Superior geology contains records of some of the most interesting cat-fights known to American science. In the present volume there is, of course, not sufficient space to even catalogue all of these valuable contributions.

The following list gives the titles of the various reports issued by the United States Geological Survey, which cover the geology and iron resources of this region:

Bayley, W. S. The Menominee Iron-bearing District of Michigan. Monograph XLVI, U. S. Geol. Survey. 513 pp. 1904.

Clements, J. M. The Vermillion Iron-bearing District of Minnesota. Monograph XLV, U. S. Geol. Survey. 463 pp. 1903.

Clements, J. M., Smyth, H. L., Bayley, W. S., and Van Hise, C. R. The Crystal Falls Iron-bearing District of Michigan. Monograph XXXVI, U. S. Geol. Survey. 512 pp. 1899.

Irving, R. D., and Van Hise, C. R. The Penokee Iron-bearing Series of Michigan and Wisconsin. Monograph XIX, U. S. Geol. Survey. 534 pp. 1892.

Leith, C. K. The Mesabi Iron-bearing District of Minnesota. Monograph XLIII, U. S. Geol. Survey. 316 pp. 1903.

Van Hise, C. R., Bayley, W. S., and Smyth, H. L. The Marquette Iron-bearing District of Michigan, with Atlas. Monograph XXVIII, U. S. Geol Survey 608 pp. 1897.

Van Hise., C. R., and Leith, C. K. The Geology of the Lake Superior Region. Monograph LII, U. S. Geol. Survey. 641 pp. 1911.

The series above noted comprises about thirty-six hundred quarto pages, and furnishes a fair summary of the more important facts relative to the geology of the Lake Superior district.

As for the engineering and industrial problems which have arisen and been solved during the development of the Lake district, numerous reports and articles are to be found in the transactions of the Lake Superior Mining Institute and the American Institute of Mining Engineers; and in the files of the *Iron Trade*

Review and the *Iron Age*. The following brief list contains the titles of a few publications which have a special value in connection with the industrial history and development of the region.

Brooks, T. B. Iron Regions of the Upper Peninsula of Michigan. Reports Michigan Geological Survey, vol. I, pp. 1–319. 1873. Invaluable data on early history, smelting and mining methods, etc.

Crowell, B., and Murray, C. B. The Iron Ores of Lake Superior. 186 pages. 1911. Covers summary of geology, etc., but particularly methods of sampling, analyses, prices, etc.

Finlay, J. R. Report on Appraisal of Mining Properties of Michigan. 65 pages. 1911. Published by Michigan Tax Commissioners.

Hurd, R. Iron-ore Manual, Lake Superior District. 162 pages. 1911. Covers particularly prices, sampling, analyses, etc.

Mussey, H. R. Combination in the Mining Industry; a Study of Concentration in Lake Superior Iron-ore Production. Vol. 23, Columbia University Studies in Political Science. 167 pages. 1905.

THE CLINTON ORES OF SOUTHERN WISCONSIN

At the beginning of this chapter it was noted that one district in Wisconsin produced ore different in every way from the Lake ranges proper. This district is located near Mayville and Iron Ridge, in Dodge County, southeastern Wisconsin.

The ores here are oölitic hematites, corresponding closely in origin, age, character and grade to the well-known Clinton hematites of the Birmingham district of Alabama. The workable beds vary considerably in total thickness from point to point in the Dodge County area, the aggregate ranging from 4 feet up to 20 feet or more. The greater thicknesses reported from some points on the outcrop appear to be due, in part, to the inclusion of loose ore. Leith and Van Hise, in Monograph LII, U. S. Geological Survey, suggest an average thickness of 10 feet for the entire area. On this basis, they estimate the total tonnage of ore in the field at six hundred million tons.

As to grade and composition, the beds show considerable variation, but the shipping average is kept quite close around 45 percent iron, dry basis. The handbook of the Lake Superior Iron-ore Association gives the following analyses from the two mines of this district, as representative of the average of shipments during 1911.

ANALYSES OF WISCONSIN CLINTON ORES, 1911

Constituent	Mayville mine, natural	Mayville mine, dry basis	Iron Ridge mine, dry basis
Metallic iron	41.15	45.97	46.39
Manganese	0.16	n. d.	n. d.
Silica	4.93	5.51	5. 34
Alumina	3.89	4.35	n. d.
Lime	5.46	6.10	n. d.
Magnesia	2.66	2.97	n. d.
Sulphur	0.037	0.041	n. d.
Phosphorus	0.851	0.951	1.624
Loss on ignition	9.81	10.96	n. d.
Moisture at 212° F	10.48	0.00	0.00

From these analyses it will be seen that the ores, like Clinton ores in general, are characteristically high in phosphorus.

CHAPTER XVIII

IRON ORES OF THE SOUTHERN UNITED STATES

During the past few years both professional and public attention has been attracted toward the iron ores of the southern United States, to such a degree that at times the unwonted—and unwanted—publicity has become embarrassing rather than advantageous to those engaged in mining and smelting these ores. In spite of all the political and legal discussion of various phases of the subject, there still seems to be need of a brief summary of the commercial and geological relations of the southern iron ores; and that will be attempted in the present chapter. The past decade has afforded a large supply of detailed reports on individual properties or on particular districts, and it will be of advantage to use the data now available in such a way as to bring out the more general features of the subject. In doing this the writer has drawn freely from his own notes as well as from published descriptions of the various fields.

CERTAIN LIMITATIONS AND ADVANTAGES

Before taking up the discussion of individual ore districts, it will be well to make certain general statements regarding southern ores, in an attempt to clear up misapprehensions which still exist. The principal points to which attention should be drawn, in this connection, are as follows:

1. At an early stage in southern iron development, and before the Mesabi ore had begun to supply the northern markets, there was a widespread idea that somewhere in the South it would be possible to develop ores in such tonnages, and under such traffic conditions, as to make them available as an auxiliary supply for Pittsburgh and Ohio furnaces. This theory has cost a good deal of money in the way of exploration, and is still encountered. It will clear up matters if we take it for granted that, with two exceptions, no southern ore fields are likely to be of any use along this line. The two exceptions are (a) the Texas brown ore field,

which will be discussed later in this chapter; and (b) a Virginia-West Virginia field, which promises a fair tonnage of rather low-grade ore. The Texas shipments are feasible to-day; the other field mentioned is merely a possibility of the future.

2. The second point requiring attention is the phosphorus content of the southern ores. With a few unimportant exceptions, no ores approaching Bessemer grade occur anywhere in the South. It is true that samples showing low phosphorus can be obtained at many localities; but there is no serious tonnage of such ores available anywhere. This point is mentioned because it is still a cause of useless expense to optimistic investigators.

3. The two points so far mentioned have been warnings against undue optimism; but the northern-trained engineer is usually too conservative with regard to the question of tonnages, so that a warning in the other direction will be timely. In this connection we can fairly say that, in dealing with southern red ores, we are dealing with the most continuous and, in general, the most uniform ores known anywhere; and that when this fact is realized we can hazard tonnage estimates on data which would be too scanty to serve as a fair basis in dealing with ores of any other type. With regard to brown ores, the case is different, but even here careful work will usually prevent any serious and expensive error.

4. The final point to be borne in mind is that all of these ores are still cheap, when compared with equally good ores anywhere else in the United States. This allows a great deal of detailed examination to be carried out, before buying or developing a southern ore property, without running up the total cost of the ore, in the ground, to over a few cents per ton. Under these circumstances, there is little excuse for hasty or careless purchases; and it is generally possible to have a very definite idea as to total tonnage and average grade before much money has been sunk in the transaction.

PRINCIPAL SOUTHERN ORE FIELDS

It would, of course, be possible to take up the iron-ore resources of the South state by state, and supply descriptions of most of the known deposits, for an immense amount of data is now avail-

able on these subjects. But in doing this, the details introduced would inevitably prevent the reader from obtaining any clear idea of the general situation. In order to avoid confusion, it seems therefore best to describe the ores simply in their larger and more general grouping, and to precede this discussion of the principal ore areas by a few words as to the principal types of the ores themselves.

Southern iron ores, as now mined and used, include red and specular hematites, brown ores, and magnetites. The same mineralogical species are present, therefore, as have been long familiar to northern furnacemen. But the proportions of the different types, and their relative importance, are strikingly different in two parts of the country. Hard hematites and magnetites, so common in the Lake, Highland and Adirondack areas are of little present importance in the South, though deposits of ore of these kinds are known to exist, are now mined, and may become of greater importance. But as things stand now, the chief southern ores are of two types; red or Clinton hematites, and brown ores.

The following table has been prepared to show, in compact form, the distribution of the various types of iron ore in the different southern states. In this summary, S denotes that shipments have been made in recent years; U, that undeveloped deposits are known to exist; and O, that no ore of this type is

DISTRIBUTION OF IRON ORE IN SOUTH

State	Magnetite	Specular hematite	Clinton or oölitic hematite	Brown ore
Alabama	U	*U*	*S*	*S*
Arkansas	U	U	O	U
Florida	O	O	O	O
Georgia	U	U	*S*	*S*
Kentucky	O	O	S	*S*
Louisiana	O	O	O	U
Maryland	U	U	U	S
Mississippi	O	O	O	U
Missouri	S	*S*	O	*S*
North Carolina	*S*	U	O	U
Oklahoma	U	U	O	U
South Carolina	U	O	O	O
Tennessee	U	O	*S*	*S*
Texas	U	U	O	*S*
Virginia	*S*	*S*	S	*S*
West Virginia	O	O	U	*S*

known to exist in the given state. A further attempt is made to indicate roughly the relative importance of the deposits. When the deposits of any type are of large size or otherwise of high commercial importance, whether now being worked or not, they are indicated by *italic* letters *S* or *U*.

The red hematites are by far the most characteristic, as well as the most important, of southern iron ores. They occur as distinct stratified beds in the Clinton formation of Silurian age, and throughout a large portion of the southeastern United States workable ore beds of this type will be found wherever rocks of that formation are exposed. The red ores are known locally as red, fossil or oōlitic ores, according to their more prominent characteristics in any given locality. The ore beds extend almost uninterruptedly from Virginia to central Alabama, outcropping along the eastern edge of the Cumberland plateau, and being therefore almost always within easy reach of workable coal beds. They are developed in greatest thickness in the Birmingham region of northern Alabama; but are commercially workable elsewhere in Alabama, as well as throughout most of northwest Georgia, eastern Tennessee, and at a few points in Virginia. At and near the surface the action of surface waters has leached out most of the lime carbonate which the red ores originally contained. The ores near the outcrop are therefore usually low in lime, and relatively rich in iron, ranging often as high as 50 to 60 percent metallic iron. But this is purely a surficial phenomenon, and when the beds are followed underground to a point where leaching has not occurred, the ore is found to carry considerable lime carbonate, and to range from 30 to 40 percent in metallic iron.

The brown hematites, or brown ores as they are more simply called, are hydrated iron oxides, carrying even when pure from 10 to 15 percent of combined water. A brown ore running 55 percent metallic iron would therefore be usually a much purer material than a hard hematite or magnetite carrying the same iron percentage. The brown ores however occur usually in very irregular deposits, and almost inevitably require concentration to bring them up to their normal commercial grade of 40 to 50 percent metallic iron. Much better concentrating work would be easily possible but is not at present justified by the ordinary price of southern pig iron. As to geographic distribution, brown ores are of so wide occurrence that at first sight it may seem impossible

to group the deposits in any comprehensive way. But after longer acquaintance with the subject it will be found that by far the bulk of our present brown-ore output, as well as most of that which will be utilized in the near future, comes from one of three large areas. These important brown-ore districts are respectively:

1. In the Appalachian Valley, and its foothills, extending from the northern line of Virginia to central Alabama.
2. In northwestern Alabama, middle Tennessee and western Kentucky, along the Tennessee River drainage area.
3. In northeastern Texas.

In all of these districts brown-ore deposits of large size occur, and the total tonnages available are very large, ranging in the hundreds of millions of tons. The districts differ among themselves in the character and associations of their ores, and in their present degree of development, and can therefore be discussed separately with more clearness than if we attempted to consider all the southern brown ores at once.

Finally, it is necessary to mention the occurrence of deposits of magnetite and specular hematite along the Blue Ridge and related areas in central Virginia, the western portion of the Carolinas, and central Georgia and Alabama. Most of these deposits are badly located so far as fuel and transportation are concerned, so that they have not been seriously developed except at a few points. But their concentrating possibilities are such that they offer much hope for the near future.

The main types of iron ores used in the south have now been noted, and their general distribution has been outlined. These facts can be used as a convenient basis for further descriptions.

In describing the principal southern ore fields, it will therefore be possible to group them as follows:

1. Red or Clinton ores.
2. Brown ores; Appalachian region.
3. Brown ores; Tennessee River region.
4. Brown ores; northeast Texas.
5. Magnetites and allied ores.

It is true that this grouping omits some ores which have been of importance in the past, or may become important in the future. But it covers substantially all of the tonnage now used, and the isolated deposits which do not fall in any of the groups named can safely be disregarded in any general discussion of the subject.

THE RED OR CLINTON HEMATITES

The red or Clinton hematites, which are now to be taken up in slightly more detail, are the backbone of the southern iron and steel industry. They occur in enormous tonnages, reaching well into the thousands of millions of tons; they are usually cheaply mined; they are commonly very uniform in composition and character; and their grade, in view of all industrial conditions, is very satisfactory. This last statement does not mean that they ever show high percentages of metallic iron, for they do not, their normal range being from 33 to 40 percent iron. But in most of their developed area, the Clinton red ores carry high percentages of lime carbonate, so that their silica is not as high as the low iron content might seem to indicate. This, as well as a number of more directly commercial factors, must be taken into account when a comparison is drawn between these ores and other ores of a more siliceous type.

In an earlier paragraph the geographic distribution of the red ores was briefly outlined, and it will now be profitable to recur to this phase of the matter. Before taking up the question of their distribution in the south, it may be well to note that ores of exactly similar type and age have long been known and worked in New York, Wisconsin and Nova Scotia; while the oölitic ores of the Newfoundland and Lorraine-Luxembourg districts are closely similar in type but different in geologic age. We are dealing, therefore, with a very widespread type of ore, and with one which to-day is the main supply of the Canadian, German, Belgian and French steel industries. Ores of purely sedimentary origin are, in fact, of far more importance, both as regards tonnage and industrial use, than would be suspected on reference to an ordinary text-book on ore-deposits.

The bulk of the red oölitic ores with which we are now concerned are associated with rocks of Silurian age, and occur as definite beds in the so-called Clinton formation. In the southern United States, Clinton rocks outcrop along the eastern flank of the coal fields, from Maryland to Central Alabama. The ore beds are almost continuous throughout this great extent, though in Virginia there are few points at which they attain workable thickness and grade. Through eastern Tennessee, however, the red ores become of importance, and in Alabama they reach

their maximum thickness and, in general, their best grade. Careless overestimates of their grade have, in the past, led to bitter disappointment and heavy loss, as a mere mention of Big Stone Gap, Middlesboro, Fort Payne and Gadsden will serve to recall; but as against that we may fairly set Birmingham, Ensley, Rock-

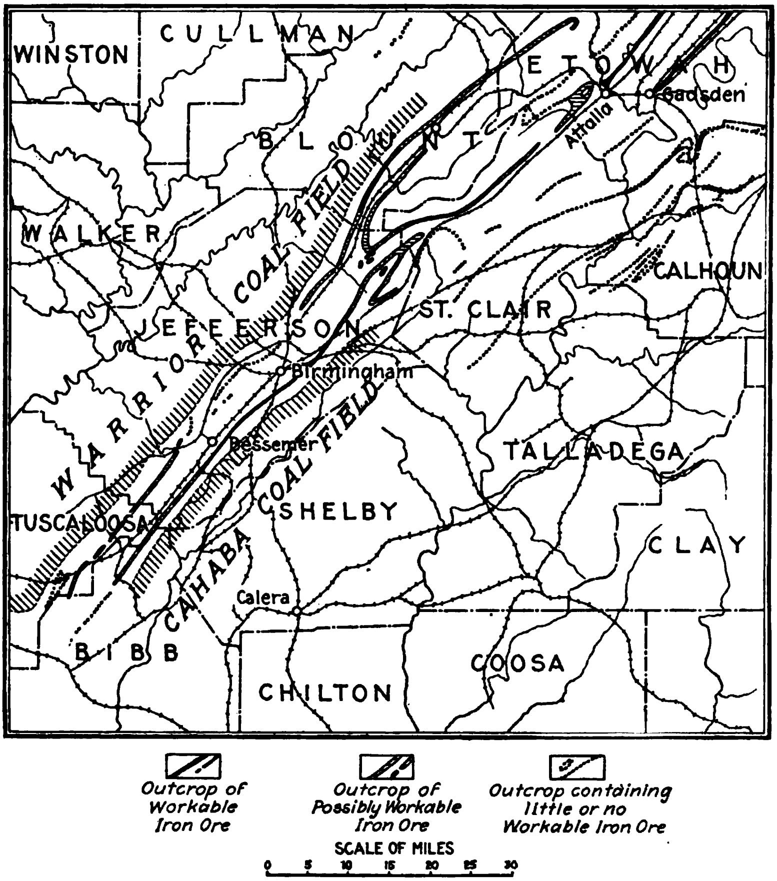

FIG. 29.—Map of Birmingham district, Alabama. (Modified from Burchard.

wood and a number of other successful iron manufacturing localities where these ores have been the main source of supply. Birmingham, of course, represents the Clinton ore at its best development.

The distribution and industrial relations of the southern red ores can be best understood if we take up separately the three districts into which it is convenient to group them. Birmingham will be first discussed in some detail, after which the Chattanooga-Attalla region and the Tennessee-Virginia area may be treated in more summary fashion.

Birmingham District.—In the Birmingham district the Clinton formation shows, at almost every point where it is carefully examined, from three to five distinct beds of red ore. Only

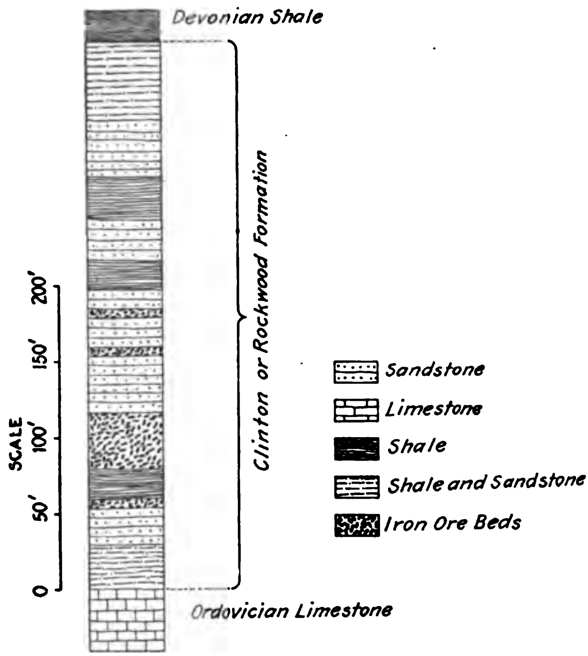

Fig. 30.—Generalized geologic section in Birmingham district.

two of these, however, are of sufficient extent, grade and continuity to be seriously considered as factors in the ore situation. The two important beds or seams have been named respectively the Irondale Seam and the Big Seam, Of these the Big Seam is the thickest and most extensive. It lies above the Irondale geologically and topographically, the interval between the two varying from 1 to 10 feet, and being occupied by shale and occasionally sandstone beds.

The Big Seam itself varies from 15 to 30 feet in thickness, but of this total only from 7 to 12 feet of ore are good enough to work at present. Throughout most of the district the lower portion of the Big Seam is too low grade for present use. The Irondale Seam ranges from 4 to 6 feet in thickness in the area where it is worked. Further data on these two seams, as they are developed in the more important portion of the Birmingham district, are quoted from Bulletin 400, United States Geological Survey, in the accompanying table.

TABLE.—EXTENT OF IRONDALE AND BIG SEAMS, WITH CHEMICAL ANALYSIS OF THE ORES

Ore seam and locality	Length of outcrop, feet	Minable ore at outcrop, feet	Dip in Red Mountain degrees	Average composition (hard ores) Fe, percent	SiO_2 percent	CaO, percent
Irondale Seam:						
Morrow Gap to Bald Eagle.	11,000	4.25	15–18	35.14	31.23	4.55
Bald Eagle to Red Gap.....	15,000	4.5	15–18	33.67	22.54	12.89
Red Gap to Helen-Bess.....	18,200	4	15–20	35.81	25.57	8.48
Helen-Bess to Hedona......	6,800	3.5	17–22	36.12	19.60	14.29
Big Seam:						
Bald Eagle to Red Gap.....	15,000	7	15–18	35.87	26.54	10.92
Red Gap to Helen-Bess.....	18,200	8	15–20	34.77	30.91	7.73
Helen-Bess to Hedona......	6,800	10	17–22	32.01	32.81	8.51
Hedona to Walker Gap.....	14,500	10	20–25	35.40	25.90	9.50
Walker Gap to Graces Gap.	5,000	12	20–25	36.26	19.02	13.50
Graces Gap to Spring Gap..	11,700	9.5	18–25	34.90	14.86	16.12
Spring Gap to Woodward No. 2....................	14,200	9	18–32	36.97	12.58	16.98
Woodward No. 2 to Readers Gap.....................	15,500	10.75	20–30	35.10	10.64	19.31
Readers Gap to Potter.....	10,000	8.5	18–40	35.44	11.20	18.25
Potter to Sparks Gap.......	5,200	5.5	30–45	33.28	12.18	19.41

All of the red-ore mines in the Birmingham district started originally as open cuts along the outcrop, the product being at first soft, or leached ore, taken out by hand labor. At a few points in the district mines of this simple type are still in operation, but in most instances they have gone much further, and are now completely underground operations, operated by slopes or inclines. In the near future we may expect to find a third type of mine developed, operated by shafts.

The ore beds on Red Mountain dip eastward at angles of 15 to 30 degrees. In the average mine the workings consist of a slope driven down the dip in the ore, with entries turned off at intervals from this slope. At several points on the mountain,

however, ravines have conveniently cut through the ore and exposed the ore beds for some distance along the sides of the ravines. In such cases, it is possible to replace the underground slope by an inclined track laid in the ravine, while drifts run into the banks at intervals take the place of the entries. In either case the ore is worked out in rooms, and the pillars are finally recovered. The total cost per ton of ore at the mouth of the mine may range from seventy-five cents to ninety cents the difference being largely in the amounts charged off for amortization, and the manner in which the mine and its machinery are kept up. Extreme parsimony in these directions makes a good showing for a few years, but is apt to have painful results later. All the ore now shipped from the Red Mountain mines is crushed to a convenient furnace size at the mine tipple, and at

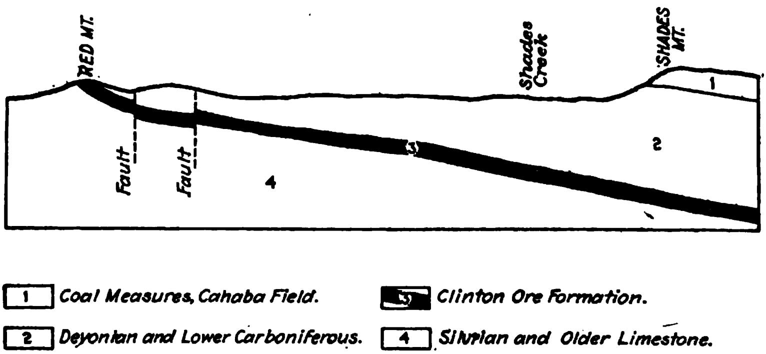

Fig. 31.—Section across Red Mt. to Shades Mt., Birmingham district (Ellis and Jordan.)

present no concentration of any kind is practised. The fact is, however, that in addition to the large reserves of commercial ore which are known to exist, there are also several thousand million tons of lower grade ores in the district which may, at some future date, be worth concentrating up to a profitable grade.

Publications on Birmingham District.—The following list contains titles of the more important publications relative to the ore deposits or iron industry of the Birmingham district.

Armes, E. The Story of Coal and Iron in Alabama. 8vo, 580 pages. Birmingham, 1910.

Burchard, E. F., and Butts, C. Iron Ores, Fuels and Fluxes of the Birmingham district. Bulletin 400, U. S. Geol. Survey, 204 pages. 1910.

CRANE, W. R. Iron Mining in the Birmingham District. *Eng. and Mining Journal*, Feb. 9, 1905.
ECKEL, E. C. Origin of the Clinton and Brown Ores of the Birmingham District. Bulletin 400, U. S. Geol. Survey, pp. 28–39, 145–150. 1910.
HIGGINS, E. Iron Operations of the Birmingham District. *Eng. and Mining Journal*, Nov. 28, 1908.
PHILLIPS, W. B. Iron Making in Alabama. Bulletin Ala. Geol. Survey, 1912.

Chattanooga-Attalla Region.—For some distance north of the immediate Birmingham district little development has taken place on the red ores. But from the vicinity of Attalla and Gadsden (Alabama) north to Chattanooga a number of mines are now in operation or have been worked recently. These mines have supplied furnaces located at Gadsden, Attalla, Fort Payne, Battelle, Rising Fawn and Chattanooga. Of this list, only the furnaces at the extreme northern and southern points—Chattanooga, Attalla and Gadsden—seem to require consideration as future iron producers.

The ores of the Chattanooga-Attalla region occur mainly as a broad flat syncline or basin underlying Lookout Mountain. The mines have been opened on the two exposed outcrops of this basin, along the east and west flanks of Lookout Mountain respectively. The total tonnage of the area, if we included all the ore which unquestionably underlies the mountain, would be enormous. On the other hand, the beds are relatively thin, and it is unlikely that the deeper levels will be operated in this district as they must some day be worked at Birmingham. Under these circumstances it will be best to confine tonnage setimates to such portions of the outcrop as show fairly workable ore beds, and to restrict our estimates in depth to some conventional level. Even a depth of 1000 feet gives tonnages ranging well up in the hundreds of millions.

The chief developments of this region have taken place at Attalla, Crudup and Porterville mines, on the west side of Lookout Mountain, and at Gadsden, Bronco and Estelle along the mountain's eastern flank. The Dirtseller and Taylor Ridge mines are located on outlying deposits east of the main mass.

The following publications refer to the Clinton ores of northern Alabama and Georgia.

BURCHARD, E. F. Tonnage Estimates of Clinton Ore in the Chattanooga District. Bulletin 380, U. S. Geol. Survey, pp. 169–187. 1909.

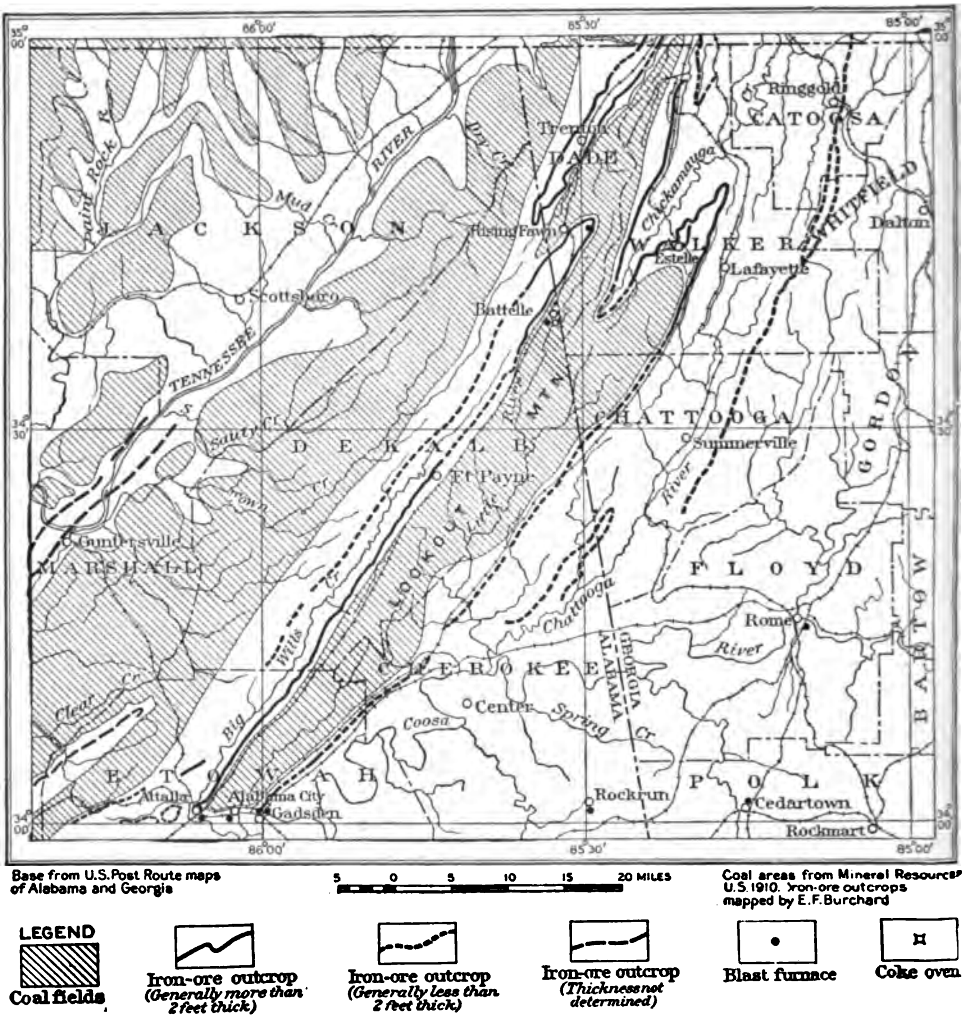

FIG. 32.—Map showing relation of outcrops of red iron ore to coal fields, transportation routes, and industrial centers in northeast Alabama and northwest Georgia. (Burchard.)

Eckel, E. C. The Clinton or Red Ores of Northern Alabama. Bulletin 285, U. S. Geol. Survey, pp. 172–179. 1906.

Eckel, E. C. The Clinton or Red Ores of Georgia. *Iron Trade Review*, January 7, 1909.

Higgins, E. Iron Operations in the Chattanooga District. *Eng. and Mining Journal*, January 2, 1909.

McCallie, S. W. Report on the Fossil Iron Ores of Georgia. Bulletin 17, Georgia Geol. Survey. 1908.

Tennessee-Virginia Region.—The main belt of Clinton ore outcrop extends northeastwardly across Tennessee from Chattanooga to Cumberland Gap, where it enters Virginia. This is a distance of 170 miles, measured directly.

The ore seams are, however, not absolutely continuous for the entire distance, being absent or at least unknown in certain portions of the belt. Furthermore, the ore beds which are known and located are, for considerable fractions of their extent, unworkable because of extreme thinness. On the other hand, for much of the distance from Virginia to the southern border of Tennessee, there are folds in the strata which result in duplication of the ore outcrop. Allowing for all of these factors, we find that the total length of Clinton ore outcrops in Tennessee is in the neighborhood of 300 miles. Of this total, about 115 miles is reported as containing an ore bed over 2 feet in thickness. From these figures it is obvious that there is an enormous total tonnage of red ore in East Tennessee; but they also suggest that it would be hazardous to indulge in very extravagant hopes as to the percentage of this total which can be considered workable in the near future.

At various points where the red ore is actually worked for furnace use, thicknesses are reported as follows: Rockwood, 2½ to 4 feet; Crescent, 5 to 6 feet; Chamberlain, 5 to 7 feet; LaFollette, 3¾ to 5 feet.

The ore varies, of course, in grade through the usual range of Clinton ores. Regarding this point Burchard states that the usual range of the hard ores used now at Tennessee furnaces is between the following limits: iron, 25 to 45 percent; lime, 8 to 20 percent; silica 4 to 15 percent; alumina, 4 to 10 percent; phosphorus, 0.25 to 0.75 percent; and sulphur, from a trace up to 1 percent.

Nine stacks use the Tennessee red ores as their principal ore supply, though commonly some brown ore is used in the charge.

The furnaces in question are Chattanooga, Citico, South Pittsburgh (2), Dayton (2), Rockwood (2) and LaFollette.

In Virginia the Clinton red ores occur in workable thickness at only a few points, and mining development has taken place on a very small scale. Beds near Cumberland Gap were once worked for the furnaces at Middlesborough, Kentucky, but have been idle for many years. More recently a red ore mine was operated by the Lowmoor Iron Company some miles south of Lowmoor station, on the Chesapeake & Ohio Railroad.

The following reports and papers refer to the Clinton ores of Virginia and Tennessee.

Burchard, E. F. Tonnage Estimates of Clinton Ores in the Chattanooga District. Bulletin 380, U. S. Geol. Survey, pp. 169–187. 1909.

Burchard, E. F. The Red Iron Ores of East Tennessee. Bulletin 16, Tennessee Geol. Survey, p. 173. 1913.

Eckel, E. C. The Oriskany and Clinton Ores of Virginia. Bulletin 285, U. S. Geol. Survey, pp. 183–189 1906.

Moore, P. N. Report on Iron Ores in the Vicinity of Cumberland Gap. Reports Kentucky Geol. Survey, vol. 4, pp. 241–254. 1878.

BROWN ORES OF THE APPALACHIAN VALLEY

The red ores which have just been discussed are sedimentary ores, occurring as definite beds inter-stratified with other rocks; and their place in the geologic system is therefore fixed very closely. The brown ores, which are now to be considered, are very different in origin and associations. They occur as scattered deposits, overlying rocks of different geologic ages, and the brown-ore deposits are of much later age than the rocks which they now overlie. They have originated, in most cases, through deposition from iron-charged waters, the deposition taking place near the ground surface, and being particularly apt to occur where beds of limestone offered a resting place for the iron minerals.

The principal brown-ore deposits of the South occur in the Appalachian Valley, or in its foothills. This limestone valley is almost continuous from Canada to Alabama, and throughout its entire extent it presents almost ideal opportunities for the formation of brown-ore deposits. Flanked on the east by iron-bearing crystalline rocks, which form the Highlands of New York and New Jersey, the South Mountain and Blue Ridge of Pennsylvania and Virginia, and similar ranges further south,

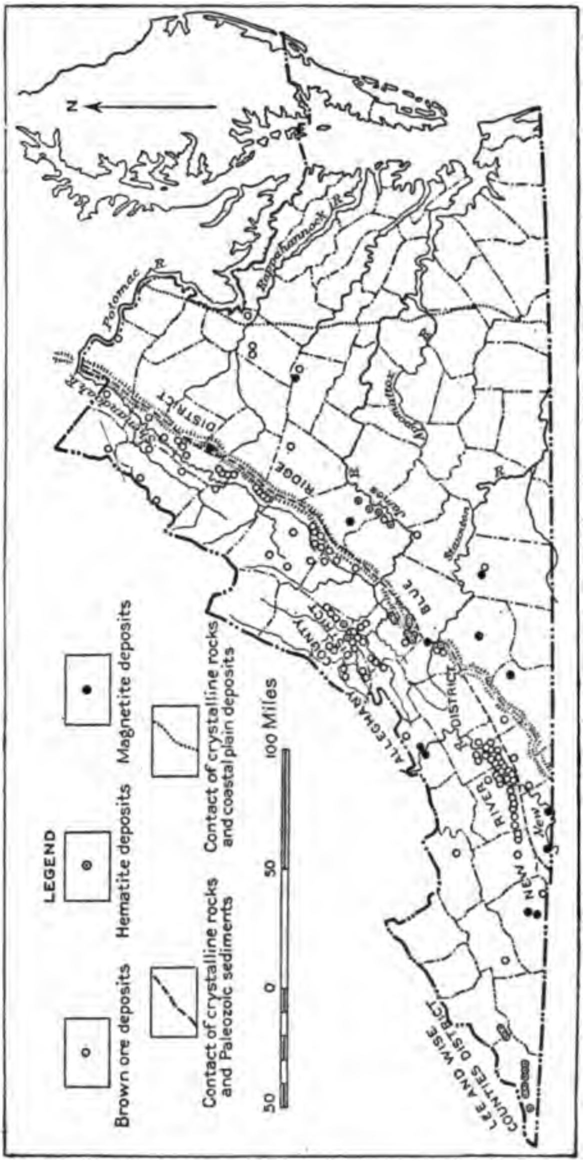

FIG. 34.—Location of iron-ore deposits in Virginia. (Harder.)

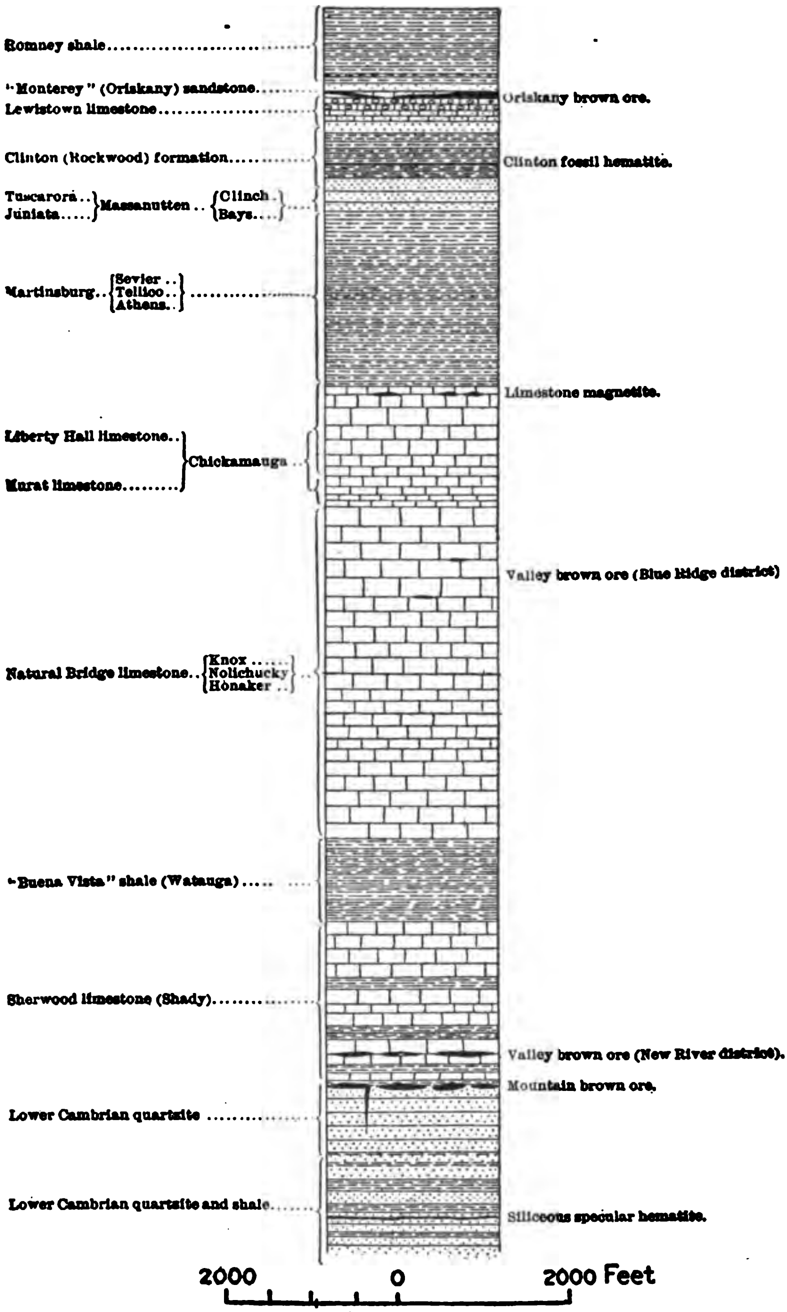

FIG. 35.—Geologic section of Appalachian Valley rocks in Virginia. (Harder.)

the progress of rock decay has for ages furnished a supply of iron-charged surface waters. The rocks of the valley itself, consisting chiefly of limestone with interbedded shales and sandstones, all containing iron in small but persistent amounts, are more immediate sources of supply. The iron-bearing waters have found excellent locations for the deposition of their iron in the valley and its foothills, whose rocks vary in composition, solubility and hardness, and dip at varying angles. The topographic features which result from these conditions have influenced the location and the type of brown-ore deposits which occur in various portions of the valley.

The net result of these geologic conditions is that now, reaching all the way from Vermont to central Alabama, we find more or

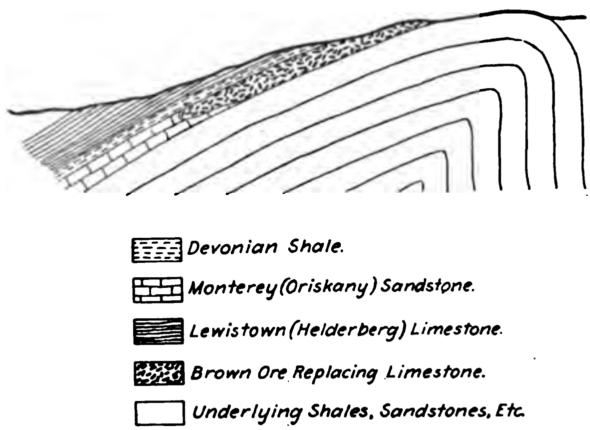

FIG. 36.—Cross-section of typical ore deposits in Oriskany district, Virginia.

less extensive deposits of brown ore scattered along the Appalachian Valley region. Occasionally workable deposits are found well out in the valley itself, but usually they occur along its flanking hills.

Throughout most of the range, the heaviest deposits are along the eastern side of the valley; but the well-known Oriskany ores of Virginia, long worked at Longdale, Lowmoor and other mines, are on its western side, and the Woodstock and Champion districts of Alabama are also west of the main limestone valley. In Tennessee, northern Alabama, northeast Georgia and south-

western Virginia, however, the brown-ore mines which have become serious shippers are principally located close to the eastern side of the valley, and in some cases the deposits lie well up on the ridges flanking the eastern edge.

In practically all cases, except in the Virginia Oriskany district, the brown ore occurs associated with limestones, shales and quartzites of Cambrian or lower Silurian age, or with the clays and other residual material derived from the decay of these rocks. The ores do not form continuous beds, but are in irregular deposits. These deposits are apt to be richest at or near the sur-

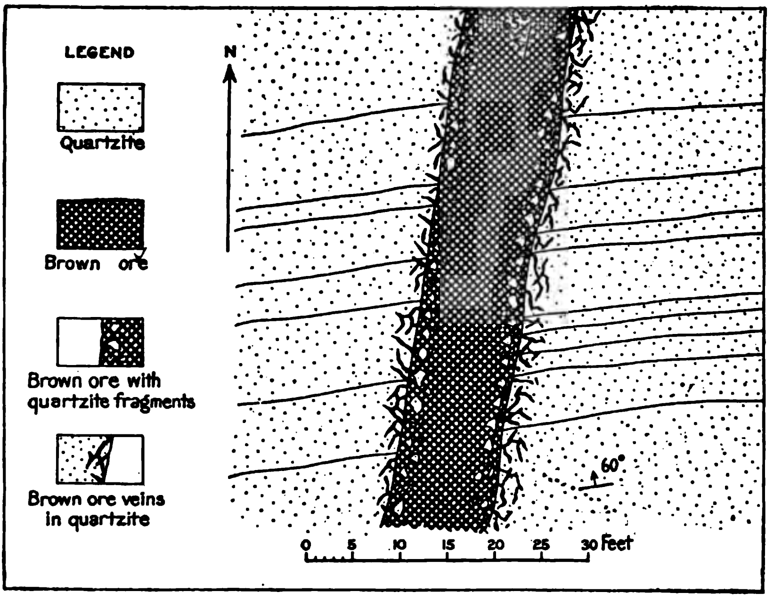

FIG. 37.—Brown ore body, Vesuvius, Va. (Harder.)

face, and to disappear entirely when they are followed deep enough to strike solid rock. Their irregularities of form and richness are very pronounced; but usually a careful study of local geologic features will enable both prospecting and working to be carried on with reasonable economy and certainty. In places, where the ores were originally concentrated along particular beds of rock, the existing deposits still show some approach to alternations of rich and barren layers; in other instances, as for example that

shown in Fig. 17, there is little approach to system in the distribution of the ore throughout the clay.

This last note brings us to another feature of brown-ore mining. The ore itself, at its theoretical maximum of purity, could conceivably carry from 60 to 66 percent metallic iron, according to the particular iron mineral which happened to form the bulk of the ore. But as a matter of fact even the most careful hand mining, in the richest deposits, rarely gives ore grading over 55 percent metallic iron; and by far the bulk of our southern brown ores, after washing and jigging, will not yield over 50 percent iron. In many districts even this grade can not be attained in a commercial way, and one important district does not give much over 42 percent iron for steady shipments.

In producing a ton of 50 percent ore, it may be necessary to mine from 2 to 15 tons of crude ore dirt, according to the district. The bulk of the Appalachian output probably comes from ores which concentrate at ratios of between 3:1 and 5:1, however. A large portion of this tonnage is produced by simple washing, without jigging; and even a casual study of the Appalachian ores will serve to show that this leaves large margin for improvement. As the Appalachian brown-ore deposits still contain, so far as can be estimated, several hundreds of millions of tons of good ore, there is obviously reason to pay more attention to questions of more careful methods of mining and concentration.

Commercially, it can be said that the Appalachian brown ores furnish the entire supply for all of the Virginia furnaces; for several in east Tennessee; and for a small group in northern Alabama and northwest Georgia; and that they furnish a part of the supply for the furnaces of the Birmingham district.

The following publications refer to the brown ores of the Appalachian Valley region, from Maryland to Alabama.

Burchard, E. F., and Eckel, E. C. Iron Ores of the Birmingham District. Bulletin 400, U. S. Geol. Survey. 1909.

Eckel, E. C. The Oriskany Ores of Virginia. Bulletin 285, U. S. Geol. Survey, pp. 183–189. 1906.

Harder, E. C. Iron Ores of the Appalachian Region in Virginia. Bulletin 380, U. S. Geol. Survey, pp. 215–254. 1909.

Hayes, C. W., and Eckel, E. C. Iron Ores of the Cartersville District, Georgia. Bulletin 213, U. S. Geol. Survey, pp. 233–242. 1903.

Higgins, E. Iron Operations in Northeastern Alabama. *Eng. and Mining Journal*, Dec. 5, 1908.

Holden, R. J. Iron Ores of Virginia. In Mineral Resources of Virginia, 1907.

Holden, R. J. Brown Ores of the New River-Cripple Creek District, Virginia. Bulletin 285, U. S. Geol. Survey, pp. 190–193. 1906.

Jarves, R. P. The Valley and Mountain Iron Ores of East Tennessee. Resources of Tennessee, vol. 2, No. 9, September, 1912, pp. 326–360.

Johnson, J. E., Jr. Origin of the Oriskany Limonites. *Eng. and Mining Journal*, vol. 76, pp. 231–232. 1903.

McCallie, S. W. The Brown Ores of Georgia. Bulletin 10, Georgia Geol. Survey, 190 pages. 1900.

Moxham, E. C. The Great Gossan Lead of Virginia. Trans. Amer. Inst. Mining Engrs., vol. 21, pp. 133–138. 1892.

Porter, J. J. The Virginia Iron Industry. Manufacturer's Record, vol. 51, pp. 717–719, 749–752, 788–790. 1907.

Singewald, J. T. Report on the Iron Ores of Maryland. Reports Md. Geol. Survey, vol. 9, part 3, pp. 123–337. 1911.

BROWN ORES OF THE TENNESSEE DRAINAGE AREA

Second to the Appalachian region so far as present developments are concerned, but probably far outranking it in unworked reserve tonnages, is the region lying in northwestern Alabama, middle Tennessee and western Kentucky, along the Tennessee River drainage, and in the areas drained by its main tributaries. This great iron region has certain interesting historical associations, for the first furnace in Alabama was built to utilize these ores; and, at the other end of the district, lies the scene of the first serious attempt at promotion by Thomas Lawson—the Three Rivers project. Scattered all over the intervening territory are the ruins of old charcoal furnaces and forges, while six or eight furnaces are still in blast on these ores in Alabama and Tennessee.

This brown-ore region lies entirely to the west of the coal fields of Alabama and Tennessee, and the ores differ in geologic associations from those of the Appalachian Valley. They are associated with limestones, it is true, but in the Tennessee area these limestones are of Lower Carboniferous age, in place of the Cambrian and Silurian limestones which are associated with the Appalachian Valley ores. Another point of difference, the result of differing geologic history of the two regions, is with regard to the attitude of the rocks and the ore deposits. In the Appalachian region the rocks have been greatly folded and tilted, so that both ores and associated rocks rarely lie in even approximately horizontal attitudes. In the Tennessee drainage

area, on the other hand, the folding and tilting have been very slight; the rocks dip at very low angles; and the brown-ore deposits mantle over them in comparatively regular form. Regular for brown ores, that is to say; for they are still highly pockety and irregular as compared with red ores or any other well-known type.

The area included in the Tennessee drainage which may fairly be expected to be productive of more or less brown ore throughout its extent is very large. From its southernmost point below Russellville, Alabama to its northern limit in Kentucky, the distance is almost two hundred miles. Its width, from east to west, varies from five to twenty miles or more. There is thus an extreme area of perhaps two thousand square miles, over which brown-ore deposits are scattered more or less thickly. Of this total area, close geologic study will probably rule out nine-tenths, as not being likely to contain any large deposits, but this leaves several hundred square miles of very promising territory within which deposits of serious size are *likely* to occur, and within which a very large tonnage of workable ore has already been developed.

As to grade, the ores of the Tennessee Basin seem to fall somewhere near the average of the Appalachian region ores. They never, for example, are as poor as the brown ores of the Virginia Oriskany district; while on the other hand they do not on the average grade as high as some of the best Virginia and Alabama Appalachian ores. The concentrating ratio is also about average. Few deposits in the Tennessee Basin will concentrate at a 5 :3 ratio, which is occasionally found further east; but on the other hand none of these Tennessee Basin ores require a 10 : 1 or worse concentration, which occasionally is necessary in southwest Virginia. Taking all of these factors into consideration I should say that the Tennessee Basin now contains a far larger tonnage of brown ore which can be profitably mined and concentrated to a 48 to 50 percent grade than do all of the Appalachian Valley deposits together.

The following publications relate to the brown ores of this district.

Burchard, E. F. The Brown Iron Ores of the Russellville District Bulletin 315, U. S. Geol. Survey, pp. 152–160. 1907.

Caldwell, W. B. Report on the Limonite Ores of Trigg, Lyon and

Caldwell Counties (Kentucky). Reports Ky. Geol. Survey, vol. 5, new series, pp. 251–264. 1880.

Chauvenet, W. M. Notes on the Samples of Iron Ore Collected in Kentucky. Vol. 15, Reports Tenth Census, pp. 289–300. 1886.

Chauvenet, W. M. Notes on the Samples of Iron Ore Collected in Tenessee. Vol. 15, Reports Tenth Census, pp. 351–365. 1886.

Eckel, E. C. Origin of the Russellville Ores. Bulletin 400, U. S. Geol. Survey, pp. 149–150. 1910.

Hausmann, F. W. Brown Ore Mining in the Russellville District. *Stevens' Institute Indicator,* January, 1908.

BROWN ORES OF NORTHEASTERN TEXAS

The brown-ore field of northeastern Texas covers a very extensive area, deposits being known to occur in at least the following twenty counties: Camp, Cass, Marion, Morris, Upshur, Wood, Harrison, Van Zandt, Gregg, Panola, Smith, Rusk, Cherokee, Henderson, Anderson, Houston, Nacogdoches, Shelby, Sabine and San Augustine. Within this field Kennedy has mapped iron-ore districts aggregating over 1000 square miles in area. There is no question whatever as to the areal extent or large total tonnage of the ore cocuring in this field, and estimates of total reserves ranging 500 million up to 1,000 million tons may be accepted as well within the truth. The possibility of commercial utilization depends upon factors other than total tonnage.

The ores occur in approximately horizontal beds, associated with clays, sands and greensands of Tertiary age. The ore-bodies are conformable to the associated beds and often are enclosed in them, but this is not necessarily proof that the ores originated at the same time as the associated sediments. On the contrary, the probability seems to be that the ores, as now found, were formed at a somewhat later period than the associated sands and clays, though these formations probably contributed some or all of the iron needed for the ores. To the miner the question of origin has, in this case, but one practical bearing, in other words, on the probability of finding in depth richer or larger deposits than those now exposed at the surface or in shallow diggings. This point fortunately is not involved in any theoretical differences of opinion as to the origin of the Texas brown ores. Under any probable hypothesis it may as well be understood clearly that—

(1) As to size of deposit, there is no probability that thicker beds will occur at deeper levels, and

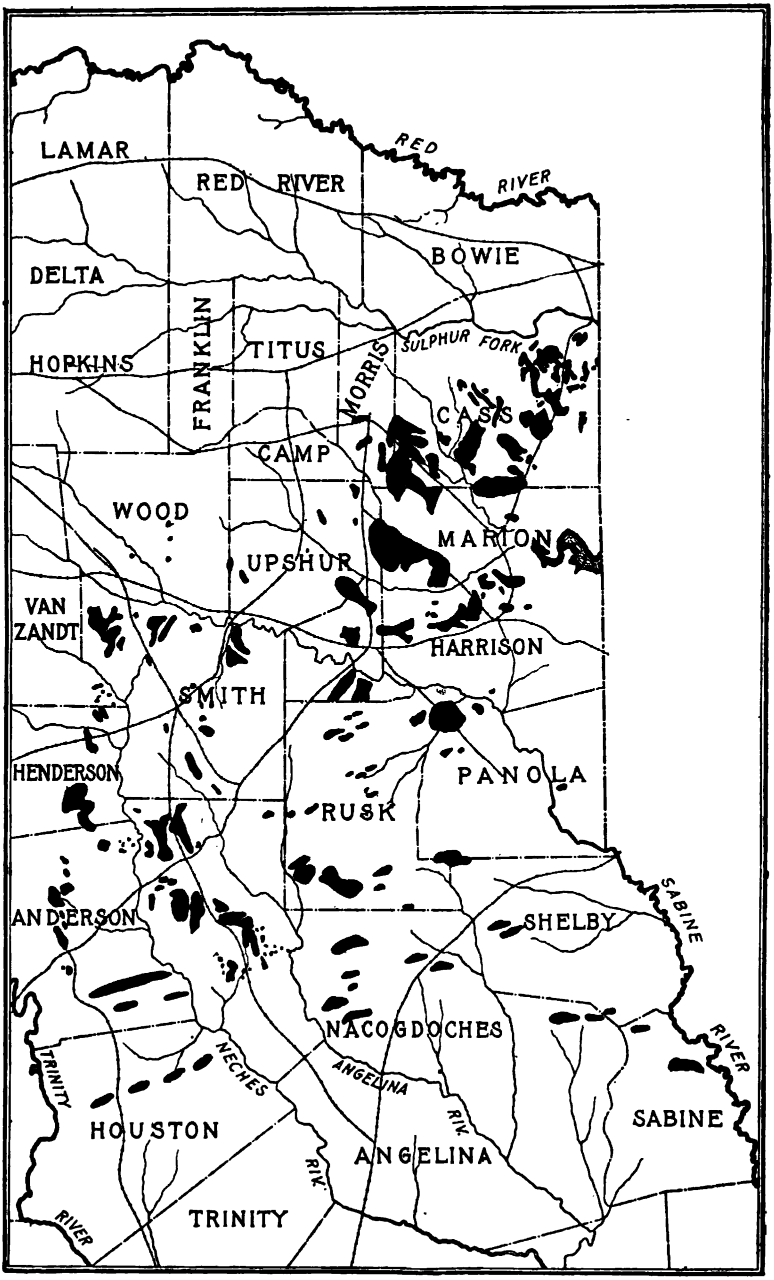

Fig. 38.—Map of Texas brown-ore district. (Kennedy.)

(2) As to richness of ores, the chances are that the richest ores will be found at or near the surface.

Ore Formation.—The ore occurs in the form of relatively large nodules, or in platey layers, and in either case can be readily and thoroughly cleaned from the accompanying sand. The ore fragments themselves, however, contain fine sand grains, so that the silica content of the clean ore is usually higher than might be expected.

An extensive series of analyses made on samples collected by Kennedy gave the following average result: Metallic iron, 46.63 percent; silica, 14.47 percent; alumina, 8.17 percent; sulphur, 0.083 percent, and phosphorus, 0.172 percent.

This average covers the results of 131 samples, taken in every part of the Texas brown-ore area. Of course individual samples give much higher results. There are also authentic furnace records showing long runs on ore averaging 55 to 57 percent iron, but these were, in the cases examined, on ore which had been dried previous to charging. It seems probable that by care in handling, shipments could be made for large tonnages averaging about 50 percent iron, but much more should not be expected.

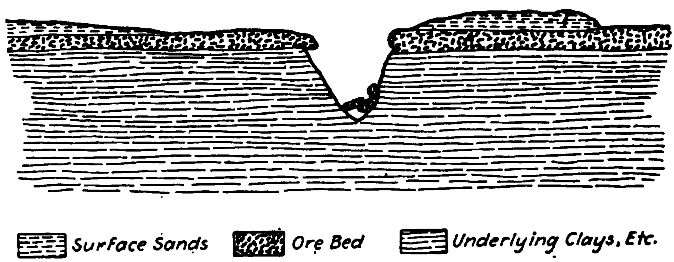

FIG. 39.—Section of typical brown-ore deposit in Texas district.

Ore Near Surface.—The ores are found on the tops of plateaus, separated by sharp little ravines. Along the sides of the ravines ore fragments often give an erroneous idea of great average thickness, but the deposits, when in place, range from 1 foot to 8 feet or 10 feet thick, and the average over the entire field will probably fall between 2 and 3 feet. In places the ore is at the surface, in others it is covered by a few inches to 5 or 6 feet of sand.

Generally, the ores are of good grade and are present in large total quantity, but thin beds. They can be mined cheaply and easily at any given point; and the whole problem is one of assem-

bling a tonnage from a series of scattered operations. Transportation to the coast is now available at a fair rate, and the ores could be laid down in Baltimore or other Atlantic Coast points at prices to compete with Cuban ores.

It must be borne in mind that, in this discussion of the Texas brown-ore situation, I have had in mind the whole field, and not any individual property. In an area of this size it is probable enough that, at some points, the ore-bodies show greater thicknesses than I have noted; and it is entirely possible that large tonnages may be mined and washed to show a higher grade than has been assumed in the preceding discussion. But these are matters of purely individual interest, and can have no bearing on the value of the field, taken as a whole.

The following list comprises the principal publications dealing with the brown ores of northeastern Texas. Kennedy's main report of 1891 is, of course, by far the most important and detailed.

Eckel, E. C. The Iron Ores of Northeastern Texas. Bulletin 260, U. S. Geol. Survey, pp. 348–354. 1905.

Eckel, E. C. The Iron Industry of Texas, Present and Prospective. Iron Age, vol. 76, pp. 478–479. Aug. 24, 1905.

Johnson, L. C. Report on the Iron Regions of Northern Louisiana and Eastern Texas. House Document No. 195, 1st session, 50th Congress. 1888.

Kennedy, W. Reports on the Iron-ore District of Eastern Texas. In 2nd. Ann. Report Texas Geol. Survey, pp. 7–326. 1891.

Kennedy, W. Iron Ores of East Texas. Trans. Amer. Inst. Mining Engrs., vol. 24, pp. 258–288, 862–863. 1895.

Penrose, R. A. F. The Tertiary Iron Ores of Arkansas and Texas. Bulletin Geological Society America, vol. 3, pp. 44–50. 1892.

MAGNETIC AND OTHER ORES OF THE CRYSTALLINE AREA

The four ore districts which have so far been considered carry ores differing in grade, origin and associations; but each of the districts is fairly uniform, within itself, in these regards. This is not the case with the group of ores which remain to be briefly mentioned, for they differ among themselves very widely in all of these respects. Their only point of agreement is in the area which includes them, and in the general type of rocks with which they are associated.

By reference to any general geological map, it will be seen that the Appalachian Valley is bordered on the east by

a wide area of crystalline rocks. These rocks, some of which are igneous and others of metamorphic origin, include slates, schists, gneisses, granites, etc. Scattered along this area we find at intervals deposits of iron ore of three general types. There are (1) magnetite deposits, often of great size and purity; (2) specular hematites, varying in grade and character, and (3) brown ores, occurring as gossan capping pyrite deposits.

Some of the ores of the crystalline area have been long worked and are well known geologically and industrially. Among these may be noted the magnetites of Cranberry, N. C.; the magnetites and hematites of Pittsville and Rocky Mount, Va.; and the brown gossan ores from Ducktown, Tenn. But in addition to these known and developed deposits, there are a large number of promising areas which are held back chiefly by lack of transportation facilities. During the past decade three new railroads have crossed the crystal line area at widely separated points—the Virginian, the Clinchfield, and the Atlanta, Birmingham and Atlantic. Each of these has opened up new iron territory, and this process of development by means of new transportation lines may fairly be expected to continue until the ores of the crystalline area become better represented among the shipments of the year.

The following papers and reports refer to the magnetites and specular hematites of this portion of the southern states.

Eckel, E. C Gray Hematites of Eastern Alabama. *Iron Trade Review*, Aug. 6, 1908.

Grasty, J. S. The Gray Ores of Alabama *Manufacturer's Record*, vol. 50, pp. 550–553. 1906.

Holden, R. J. Iron Ores of Virginia. In Mineral Resources of Virginia, 1907.

Nitze, H. B. C. Iron Ores of North Carolina. Bulletin 1, N. C. Geol. Survey, 239 pages. 1893.

Singewald, J. T. Report on the Iron Ores of Maryland. Vol. 9, part 3, Reports Maryland Geol. Survey, pp. 123–337. 1911

SOUTHERN IRON-ORE REQUIREMENTS

In the preceding sections of this chapter the iron ores and chief ore districts of the southern United States have been described, and some idea given as to the large ore tonnages which are available in some of these districts. It will be of interest to take up the question of southern ore requirements, both as these have

been in the past, and as they are likely to stand in future. In doing this, our conclusions may be based upon the growth which the southern iron and steel industry has shown, the conditions which have limited that growth, and the conditions which favor it.

Growth of Southern Iron Industry.—Statistics relative to the iron production of the United States, during the period from the Revolution until after the close of the Civil War, are scanty and difficult to handle. The chief difficulty arises from the fact that in most of the earlier statements as to production there is confusion between pig iron, bar iron made direct from ore, and iron wrought from the pig. In the South, where both forges and bloomaries were in operation until very recent years, the opportunities for error are particularly great.

So far as can be determined, the southern states made almost exactly one-fifth of the total iron produced in 1810; and this proportion increased quite steadily, reaching its maximum probably between 1840 and 1850. From this date on the southern share of the total dropped rapidly, for the Michigan ranges were now beginning to ship heavily to northern and eastern furnaces. The data available for the two decades preceding the war and for the decade following it are as follows:

Date	U. S. output, tons	Southern output, tons	Southern percentage of tota
1840	286,903	*	125.9
1850	563,775	131,541	23.4
1854	724,000	130,198	17.9
1856	812,000	124,752	15.3
1860	987,559	*	12.8
1870	1,832,875	*	8.6

The history of the Southern iron and steel industry during the war has never been written, though scattered details concerning its development in individual states can be found in different volumes, and Miss Armes has given us an adequate and interesting discussion of its status in Alabama. Here it need only be said that war was a harsh and pressing schoolmaster, and that the wonder is that southern legislators have so soon forgotten the lessons then impressed. As early as the fall of 1861 it was

* Calculated iron ore consumption or value of product.

understood that man cannot live by cotton alone; and that in modern war courage and devotion must be reinforced by material supplies if a long struggle is to be successfully prosecuted. Under the encouraging influence of the coast blockade, which was as successful as a high tariff in preventing imports, the industries of the South, heretofore neglected in favor of agriculture, grew at a really remarkable rate. Had these favoring conditions persisted, it is certain that the South would now be a great manufacturing nation, and that many idle economic theories would be looked upon as outgrown.

But the development thus started was not to continue at that time. The battles of 1862 resulted in the practical isolation of the southwestern states, and in the destruction of the west Tennessee iron industry. The furnaces and mills of southwestern Virginia and northwest Georgia kept in operation, with few exceptions, until the summer of 1864; while Brierfield and other Alabama furnace and the Selma works held on until the closing days, in the spring of 1865. As to the output, few definite data are available. In 1860 the southern states were making somewhat over 120,000 tons of pig iron annually. It is probable that during 1861 and 1862 this was greatly exceeded, but from that time on the output fell off as furnaces and mills were destroyed. I have assumed that in 1865 the south was not making over 5 percent of the American total, even allowing for the fact that the Maryland, Kentucky and Missouri furnaces had mostly escaped interference throughout the war.

The recovery after peace came was not so sudden as has been intimated by popular essayists. We know that the ghastly farce called Reconstruction did not, in fact, look toward the physical reconstruction of the ruined commonwealths; and so far as individual effort was concerned food supplies, and readily salable cotton, were more important than manufactures. In 1870, at any rate, the South had recovered only so far as to produce a little over 8 percent of the American total iron output. But in the decade which followed, progress was much more rapid, so that by 1875 the southern proportion had risen to over 12 percent, which was about held in 1880.

From this time on, there has been an almost uninterrupted growth in the annual output of Southern pig iron up to the present day, the temporary decreases shown during bad business

years being unimportant. The proportion which this Southern output bears to the American total, however, has shown greater variations. From 1880 on, this proportion increased quite regularly, reaching in 1893 its maximum of 22½ percent. After that date the ratio decreased, and during the past eight years it has ranged between 12 and 15 percent of the total output of the United States.

PIG-IRON OUTPUT 1880-1910

Year	Total U. S.	South	Ratio, Southern to total percent
1880	3,835,191	448,978	11.7
1885	4,044,526	682,359	16.9
1890	9,202,703	1,833,937	19.9
1891	8,279,870	1,738,194	21.0
1892	9,157,000	1.947,187	21.3
1893	7,124,502	1,599,659	22.5
1894	6,657,388	1,274,947	19.2
1895	9,446,308	1,729,606	18.3
1896	8,623,127	1,846,999	21.4
1897	9,652,680	1,937,229	20.1
1898	11,773,934	2,133,514	18.1
1899	13,620,703	2 398,881	17.6
1900	13,789,242	2,642,720	19.1
1901	15,878,354	2,626,387	16.6
1902	17,821,307	3,085,957	17.3
1903	18,009,252	3,287,522	18.3
1904	16,497,033	2,775,215	16.8
1905	22,992,380	3,279,370	14.3
1906	25,307,191	3,525,119	13.9
1907	25,781,361	3,493,772	13.7
1908	15,936,018	2,369,741	14.9
1909	25,795,471	3,188,091	12.4
1910	27,303,567	3,447,291	12.6

The actual tonnage annually produced in the south has increased, since 1880, from less than half a million tons to considerably over three million tons. The northern output, however, has increased at practically a similar rate, so that in 1912 the South shows little or no proportionate advance from its relative position in 1880; and a distance falling off from the position which it assumed during the early nineties. It is clear enough that the *relative* decrease shown during the years from 1893 to 1905 was

due in most part to the opening of the Mesabi range in Minnesota, which since 1892 has been sending down a steadily increasing tonnage of ore to eastern furnaces. For the past eight years, as has been previously noted, the South has just about maintained its relative position. It will be serviceable if we can determine, from some study of the raw materials and markets available, what the probabilities are as to the future growth, both relative and actual, of the Southern iron and steel industries. The matter of iron-ore supply has already been discussed, but some space may be given to consideration of Southern coal reserves.

Southern Coal Reserves.—So far as supplies of coal are concerned, the South has little reason to avoid comparison with any of the states east of the Great Plains; and when we discuss the prospects of American steel development we may, for all practical purposes, disregard the states west of the Missouri River. In the present paper, therefore, the comparisons made will refer only to the area east of the 100th meridian.

The latest figures on coal reserves which are available at the date of writing, are the summaries by E. W. Parker published in the annual volume Mineral Resources of the United States for 1911. In his report on Coal for that year Mr. Parker furnishes data on the unmined coal tonnages still remaining in the various states. These figures I have rearranged so as to better serve the purposes of the present discussion.

At the close of 1911, the Geological Survey estimates that there were still remaining in the United States, excluding Alaska, somewhat over three million million tons of coal, of all kinds. Of this enormous reserve, practically two-thirds exists in the area west of the 100th meridian, including the states of the Great Plains, the Rocky Mountains, the Great Basin and the Pacific Coast. As a basis for general manufacturing, this far western tonnage is highly important; but as related to a possible steel industry it becomes almost negligeable, for unfortunately it is not balanced by a corresponding development of iron ores in the western country. So that in our present discussion we may fairly disregard the western coal reserves, and concentrate attention of the unmined coal tonnage which still exists in the states east of the Great Plains.

In the portion of the United States to which our attention is thus limited the Geological Survey estimates a total coal reserve

of slightly over one million million tons. About half of this total occurs in the southern states, as that term is applied throughout this publication. The exact division by states is as follows:

COAL RESERVES OF THE SOUTH

State	Tons
Alabama	68,572,000,000
Arkansas	1,839,000,000
Georgia	920,000,000
Kentucky	103,771,000,000
Maryland	7,795,000,000
Missouri	39,833,000,000
North Carolina	199,000,000
Oklahoma	79,201,000,000
Tennessee	25,499,000,000
Texas	30,967,000,000
Virginia	22,380,000,000
West Virginia	149,026,000,000
Total Southern coal reserve	530,002,000,000

Of this total tonnage, practically all is good bituminous coal, though the Texas total includes a notable proportion of lignite. In the other states, however, we may fairly consider that all of the tonnage estimated is coal suitable for general manufacturing uses; that most of it can be coked if proper processes be used; and that a very large proportion of it is strictly "coking coal" as that term is applied to-day by those who think in terms of the bee-hive oven.

During 1911 the Southern States mined 117,625,019 tons of coal. At this rate of consumption, the southern coal supply would last for some three or four thousand years; so that we can contemplate a considerable increase in the rate of southern coal mining without becoming alarmed over the impending exhaustion of the coal supply. Even an ardent conservationist would find it difficult to really make much capital out of figures of this type.

One may note, in passing, just how seriously this line of reasoning affects certain investigations and prosecutions which have been much in the public eye during the past year or two. In the appraisal report of 1904, for example, the Tennessee Coal, Iron and Railroad Company was credited with the ownership, either in fee or under lease, of 1,623,639,500 tons of coal of all classes. This tonnage seems enormous, when written out in full, and it

would be an excessive supply for the ordinary citizen, purchasing coal only for domestic use. But when it is compared with the 68 million million tons which the official reports credit to the state of Alabama, the T. C. I. tonnage becomes a very small fraction of the total, amounting to about 2⅓ percent of the State's reserve. The "unparalleled and enormous" coal reserves of the Tennessee Company, which were referred to in such a way as to give the impression that they constituted an effective monopoly of the Southern coal supply, do not after all seem so large when compared with the total available tonnages. The same difficulty has arisen elsewhere, as in the western states and Alaska, where the conservation idea has been applied too rigidly to supplies of coal far beyond the necessities of the next ten thousand years.

Recurring to our immediate study, it is clear that the coal reserves of the south are so large that exhaustion of the coal supply will not be the factor to bring about a slowing down in the rate of southern steel development. The coal supplies of this section are far beyond any probable future requirements of its iron industry; they are well distributed throughout the various states; and they include a far larger proportion of strictly "coking coal" than do the reserves of any other section of the United States.

Southern Market Conditions.—Three features stand out prominently when the southern iron industry is studied from a commercial standpoint. These are (1) that until very recently all of the southern output was marketed in the form of pig iron, and that even now most of it is still sold in that form; (2) that the bulk of the output is marketed at points far from the furnace, and is subject to heavy freight charges; and (3) that the market price of southern pig is always lower, and usually much lower, than that of similar grades at northern and eastern furnaces. These three points of interest may be separately discussed, though they are all inter-related very closely.

(1) The south has always been an important producer of foundry irons, while a considerable tonnage of steel-making pig has been shipped from Virginia for conversion elsewhere. As a result, even at present considerably less than half of the total pig iron produced in the south is converted into steel at southern plants; while until quite recently the proportion thus converted

locally was even less important. Of course, so long as the acid Bessemer process was the principal steel-making method, this condition could not be changed, for low-phosphorus ores are almost non-existent in the south. But as things stand now this difficulty is done away with to a large extent, and the further development of southern steel-making will be limited not by technical factors but by questions of capital and markets. If the market becomes broad enough to justify it, we may expect that capital will in time be provided to erect steel-making and finishing plants for such furnace-groups as have supplies of ore and coal enough to justify the increased investment.

(2) The fact that local foundry development was never sufficient to take up any large proportion of the pig iron produced in the south, had of course the effect of forcing southern furnaces to ship north and west into competitive markets. Even now, with a fair degree of steel production in the south, a large portion of southern pig metal still goes to very distant markets. The extent to which this distant shipping was carried on can be best understood if we take up a specific case, and fortunately the statistics for one of the largest southern companies are available.

For many years the Tennessee Coal, Iron and Railroad Company has been one of the largest pig-iron producers in the South. During quite recent years it has also become a steel producer, but during its early history all of its product was marketed as pig iron. Its pig-iron sales now are relatively small in ordinary years, though the possibility that they will be made exerts an influence over southern market conditions. The following detailed figures of production and shipments to various markets during 1888 and 1899 are probably fairly representative of the general southern shipments during those years. They have also been reduced to percentages for convenience of comparison.

	1888		1899	
	Tons shipped	Percent	Tons shipped	Percent
New York and New England	30,567	14	75,270	10
Penn., Ohio, Ind., Ill., etc.	138,481	62	485,090	63
Southern States	50,406	22	102,735	13
Western and Pacific States	5,305	2	28,735	4
Foreign shipments	0	0	75,390	10
Total shipments	224,759	100	767,220	100

Though the management of the company pointed to these exhibits with evident pride, it is clear enough that they are not really things to be proud of, and that the distribution of shipments shown in them gives some clue to the relatively slow growth of the southern iron industry in general. During later years things improved in this regard, and for 1907 the same company distributed its total product as follows:

Sold as pig iron	315,573 tons
Converted into steel	287,254 tons
Total iron output	602,827 tons

It is probably correct enough to say that of its total iron output, 60 percent or more was in 1907 used locally, as compared with the 13 percent so used in 1899. In the past few years the percentage converted or sold locally has grown still higher, and hereafter it is probable that in good business years the entire output will be locally used.

This particular instance has been followed out in detail because the exact figures happen to be available, but it throws light on general conditions in the southern industry during the past few decades. Iron has been produced cheaply, and shipped to great distances in order to find a sufficiently broad market. This brings us directly to the price question.

(3) It might of course be said that distant shipment does not affect prices, since prices are quoted at furnace, and freight rates are added to these base prices. This would be true enough if only a small proportion of the total output of any district was sold at distant markets. But when, as in the case of southern iron, practically all of the output was sold in distant markets in direct competition with northern irons, the Birmingham price was practically the northern market price less freight. All the advantages of cheap raw materials and low assembling costs were thrown away as soon as the bulk of the product was shipped into distant competitive markets; and southern furnaces have in consequence shown less profits than those in the north. The prospects of improvement in this regard will be noted later.

Future Market Possibilities.—In discussing the market conditions which have limited southern iron development in the past, we have in reality outlined many of the points on which the

hope of future growth must depend. It is clear enough that the southern supply of raw materials is sufficient to justify a far greater iron output than now exists. It is also clear that pig iron can be made cheaply at several points in the south, though this fact is no justification for also selling it cheaply. And as regards the fact itself, unusually low figures of cost must be accepted with some caution. A company which runs its furnaces without lining, or its mines without roofs, can show good paper costs for a time; but there is a natural limit to that sort of thing, and if it is practised too long the receivers are apt to have a bad mess to clear up. There has been a good deal of misunderstanding concerning low-cost southern iron in the past, but this is disappearing as accounting methods are becoming more uniform.

For our present purposes we may assume that the bulk of the southern tonnage is produced at a total cost of several dollars per ton cheaper than the bulk of northern iron; but that market conditions in the past have been such that this lower cost did not mean higher or even equal profits per ton. It is evident that even with an ample supply of raw materials it would be difficult to find capital to finance any large expansion of the industry under such conditions. Growth of the southern steel and iron industry must depend on improvement of conditions in the territory naturally tributary to southern furnaces and mills, so that this territory is capable of absorbing an increased output at somewhat fairer prices than have prevailed in the past.

The Southern states themselves contain slightly over one-third of the population of the entire United States. Of course some of the south can be reached most economically from northern points, but on the other hand Alabama mills have some natural territory in the west, and Virginia and Maryland have market areas to the northward. So that in any general consideration of the matter we may safely assume that the territory naturally tributary to southern furnaces and mills contains one-third of the American population. But it is often overlooked that, in other regards, it is not average market ground. Its agricultural values are high, but its manufacturing is still relatively deficient; its railroad mileage until recently was below the average; and in some other respects it has in the past consumed less iron and steel, *per capita*, than the remainder of the United States. These facts are conveniently summarized in the following table, which

also serves to indicate how conditions are changing in these regards.

SOUTHERN MARKET FACTORS, 1880–1910

	1880	1890	1900	1910
Population, total	18,614,925	22,538,751	27,445,457	32,480,343
Percent., U. S.	36.9	35.8	36.1	35.3
Railroad mileage, total miles.	24,866	50,350	61,880	87,084
Percent, U. S.	26.7	30.2	31.8	35.5
Capital in manufactures, dollars.	$329,753,000	$848,868,000	$1,408,866,000	$2,884,666,000
Percent, U. S.	11.8	13.0	14.3	15.5
Annual manufactured products, dollars.	$622,840,000	$1,242,581,000	$1,860,113,000	$3,158,107,000
Percent, U. S.	11.6	13.2	14.3	15.2
Coal production, tons	7,002,254	24,925,345	54,510,460	120,856,340
Percent, U. S.	9.8	15.8	20.2	24.1
Pig-iron output, tons	448,978	1,833,937	2,642,720	3,447,291
Percent, U. S.	11.7	19.9	19.1	12.6

On examining the data presented in the foregoing table, it will be seen that the southern states have held their relative proportion of the total population quite steadily, showing only slight changes in this regard over the past thirty years. But in the factors which make for increased iron and steel consumption they have advanced very rapidly. Railroad mileage has increased from 26.7 percent of the American total in 1880 to 35.5 percent in 1910; and the relative gains in both the capital invested in manufacturing industries and in the total annual production of those industries has been particularly marked. Concurrently with these advances in industrial development, the coal production of the south has gained remarkably, as compared with that of the remainder of the United States. The iron production alone has shown no serious gain in relative status; and this fact of itself is sufficient to indicate that the southern iron market is far from being overbuilt at the present moment. With such rapid increases in general manufacturing and coal output, and with the increased railroad mileage which these advances will in turn require, it seems clear that the territory strictly tributary to southern mills and furnaces is gaining rapidly in its capacity for iron and steel consumption; and that there is every reason to believe that this gain will continue in the future. This implies that heavily increased productive capacity must be supplied very shortly, with the prospect that the returns on investment in such increased furnace and mill capacity will be attractive enough to stimulate investment.

CHAPTER XIX

THE NORTHEASTERN UNITED STATES

The northeastern district, which includes New England, New York, New Jersey, Pennsylvania and Ohio, now produces only about 5 percent of the total iron-ore output of the United States. This present rate of output, however, should not be taken as a measure of the ultimate importance of the district, for it contains reserves of ore which both in grade and in quantity are deserving of serious attention, and will become more important as the shipping grade of the Lake ores decreases.

General Distribution.—The iron ores of the northeastern district are varied in type, and widely distributed throughout the region. It is possible, however, to group the bulk of the ores under three main types, though several other less important classes also require mention. The classes, with their general distribution, are as follows;

1. Magnetite ores, occurring in the crystalline rocks of the Adirondacks and Hudson Highlands of New York, in the Highlands of New Jersey, and in southeastern Pennsylvania. These ores agree in being magnetites, and in their universal association with igneous or metamorphic rocks, but differ among themselves in origin, character and geologic relations. In most cases they require concentration, but the resulting concentrate can usually be made of high grade within commercial limits as to expense.

2. Red hematites of Clinton age, like those of the Birmingham district, are also found in large quantity in the northeastern district. Here they outcrop along a belt extending from near Rochester to near Utica, New York. South of this, the ores do not show in workable tonnage until we reach Pennsylvania, where they have been important sources of iron in the past and still contain large reserves.

3. Brown ores occur in scattered deposits in the limestone valleys of western New England, southeastern New York, northern New Jersey, and eastern and central Pennsylvania. These

ores have been extensively used locally, and in many localities would probably repay further development.

In addition to the three main types above mentioned, note must be made of the extensive though low-grade carbonate ores of Ohio, and of the red hematites of the western Adirondack region of New York.

In discussing the ores of the northeastern states, the grouping adopted will be based on both geological and commercial consid-

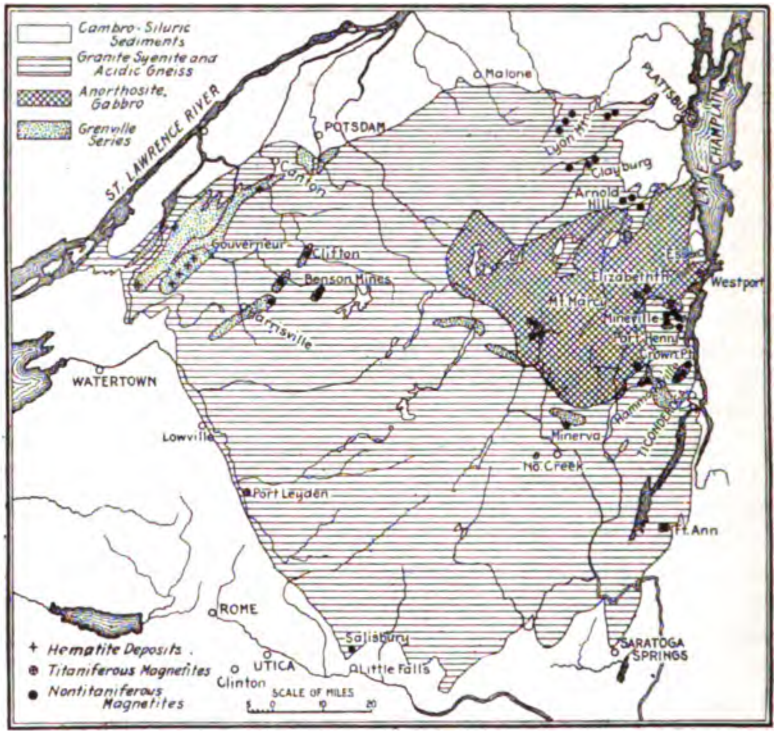

FIG. 40.—Map of Adirondack iron-ore region. (Newland.)

erations. The magnetites occur in three quite distinct areas and associations; and the magnetic ores of the Adirondacks, of southeastern New York and northern New Jersey, and of southeastern Pennsylvania will therefore be discussed separately in the order named. At present these magnetic ores are by far the most important ores of the states now under discussion. But there are also brown ore deposits of some importance, Clinton red

hematites of future promise, and a few carbonates and red hematites of other type which require brief mention. These ores will accordingly be briefly described after the magnetites.

MAGNETITES OF THE ADIRONDACK REGION, NEW YORK

The Adirondack region, in the northeastern part of New York State, comprises a roughly circular area of crystalline rocks,

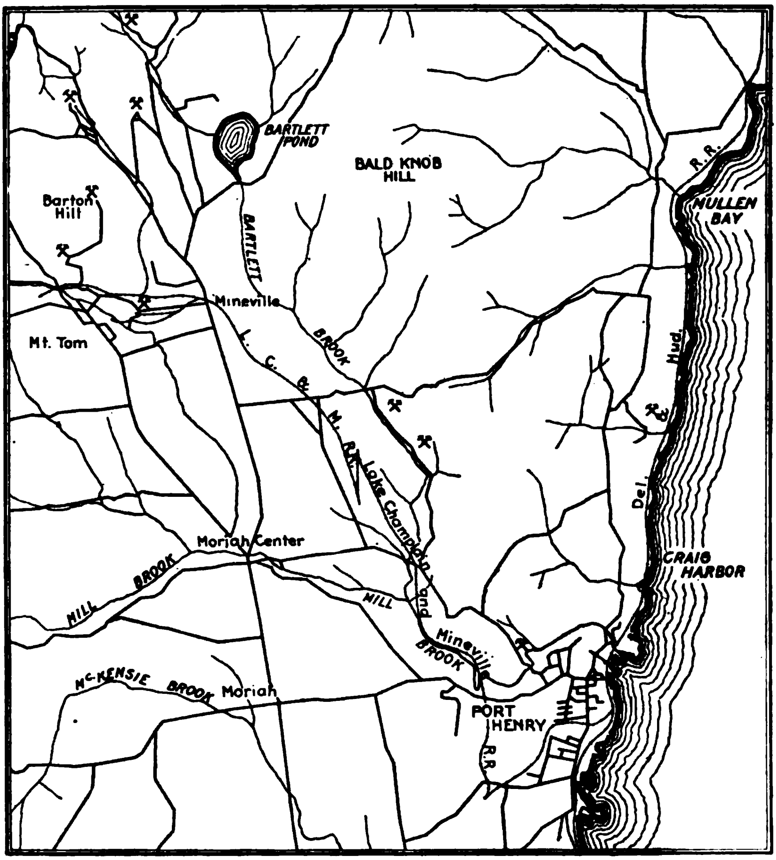

FIG. 41.—Sketch map of Mineville range. (After Kemp.)

something over 100 miles in width from east to west, and perhaps averaging about 125 miles from north to south. The entire area thus includes about 12,000 square miles at the most; and

much of this total must be looked upon as possible iron-bearing territory.

The rocks are of pre-Cambrian age; and include an old series of gneisses, a later series of schists and crystalline limestones, and igneous rocks of various ages. One particular group of these igneous rocks—a series of gabbros and other basic rocks—is of special interest as carrying the titaniferous ore-bodies of the region.

The normal or non-titaniferous magnetites are associated, in various places, both with the older gneisses and with the later schists and limestones; but the main masses now worked are

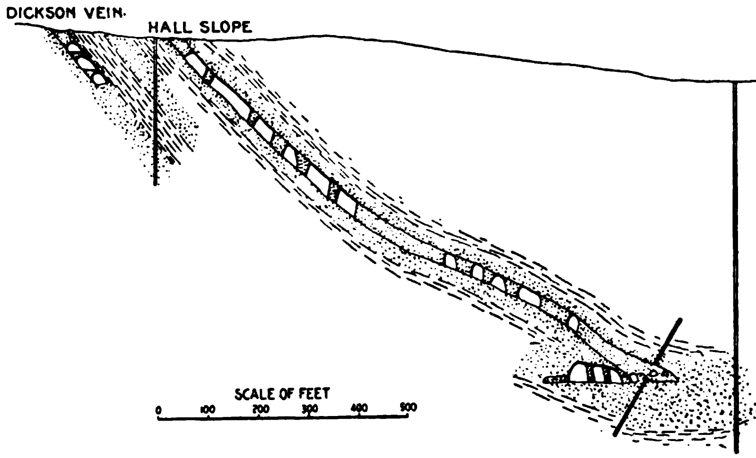

Fig. 42.—Cross-section of Lyon Mt. deposit. (Newland.)

those associated with the gneisses. The ores occur in tabular or lenticular masses, and the individual deposits can be followed for distances of miles. They have been ascribed both to direct igneous origin and to contact replacement. The field relations seem to negative the first possibility, and to suggest some type of replacement as being the more probable source of the deposits. In a few instances, it is true, the relations would even seem to suggest a more direct sedimentary origin, but study of these particular deposits is not sufficiently advanced to take this suggestion seriously at present.

The ores vary considerably, in their natural state, with regard to certain phases of composition. With the exception of a few

deposits near Lake George, they are low in sulphur. As regards phosphorus, they vary from the exceptionally low-phosphorus ores of Lyon Mountain to the high-phosphorus ores of Salisbury and Mineville. The iron content varies from the almost pure magnetite found in some of the Mineville openings down to the 22 or 25 per cent. of iron which at present is the lower limit for profitable concentration. As the Adirondack ore reserves are figured to-day, the average ore of the region would probably fall not much above 35 percent metallic iron. This means that the typical ore is about half magnetite and half gangue rock by weight.

The following publications refer to the magnetites and other ores of the Adirondack region in New York State.

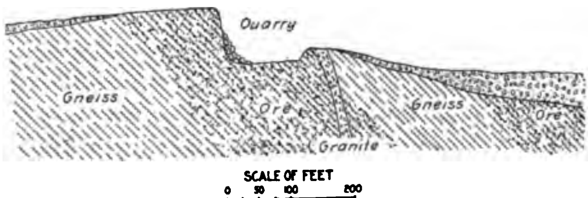

Fig. 43.—Cross-section of Benson deposit. (Newland.)

Kemp, J. F. The Geology of the Magnetites near Port Henry. Trans. Amer. Inst. Mining Engrs., vol. 27, pp. 146–203. 1897.

Kemp, J. F. The Titaniferous Iron Ores of the Adirondacks. 19th Ann. Rep. U. S. Geol. Survey, part 3, pp. 277–422. 1899.

Newland, D. H., and Kemp, J. F. Geology of the Adirondack Magnetic Iron Ores. Bulletin 119, New York State Museum. 1908.

Newland, D. H. On the Association and Origin of the Non-titaniferous Magnetites in the Adirondack Region. Economic Geology, vol. 2, pp. 763–773. 1907.

Smock, J. C. Iron Mines and Iron Ore Districts of New York. Bulletin 7, New York State Museum. 1889.

Stoltz, G. C. The Cheever Mines, Port Henry, N. Y. *Eng. and Mining Journal*, Oct. 21, 1911.

MAGNETITES OF NEW JERSEY AND NEW YORK HIGHLANDS

The Highlands of the Hudson, in Putnam and Orange counties, New York, are made up chiefly of pre-Cambrian crystalline rocks; gneisses of uncertain origin, schists and crystalline limestones, and later granites and basic igneous rocks. This belt crosses

New Jersey in a southwesterly direction. Throughout its entire extent, both in New York and New Jersey, it contains numerous deposits of magnetite. Some of these have been worked for considerably over a century, and are still producing. The importance of the district, minimized for a time by developments elsewhere, is likely to increase in a moderate way during the next period of iron expansion.

Any adequate explanation of the origin of these magnetite deposits must take into consideration certain structural and other relations which they exhibit almost universally (1) their flattened, lens-like or bed-shaped form, (2) their general conformity to the foliation of the inclosing rocks, (3) their occurrence along certain definite belts whose trend is closely parallel to the strike of the inclosing rocks, (4) their frequent (or general) association with bodies of crystalline limestone.

A brief consideration of these general relations will serve to show that it would be difficult to reconcile them with any theory involving the direct igneous origin of the magnetite deposits. Elimination of the group of theories based upon igneous origin leaves two general types of origin to be considered—direct sedimentation and replacement. Of these two alternative hypotheses the evidence seems to be strongly in favor of the latter. Differences of opinion are of course possible as to the details of the process, but the general method seems quite clear, the usual close association of the magnetites with limestone or other readily replaceable rocks being of interest in this connection. Even in the cases where no bodies of limestone are now to be found with the magnetite, it seems a fair assumption that such limestone beds once existed, and that the replacement process has here been carried to its limit, removing all traces of the replaced rock.

The following papers and reports refer to the magnetites of the Hudson Highlands of New York, and of northeastern New Jersey.

Bayley, W. S Iron Mines and Mining in New Jersey. Vol. 8, Reports New Jersey Geol. Survey, 1910.

Koeberlin, F. R. The Brewster Iron-bearing District of New York. Economic Geology, vol. 4, pp. 713–754. 1909.

Smock, J. C. Iron Mines and Iron Ore Districts of New York. Bulletin 7, New York State Museum, 1889.

Spencer, A. C. Genesis of the Magnetite Deposits in Sussex County, New Jersey. *Mining Magazine*, vol. 10, pp. 377–381. 1904.

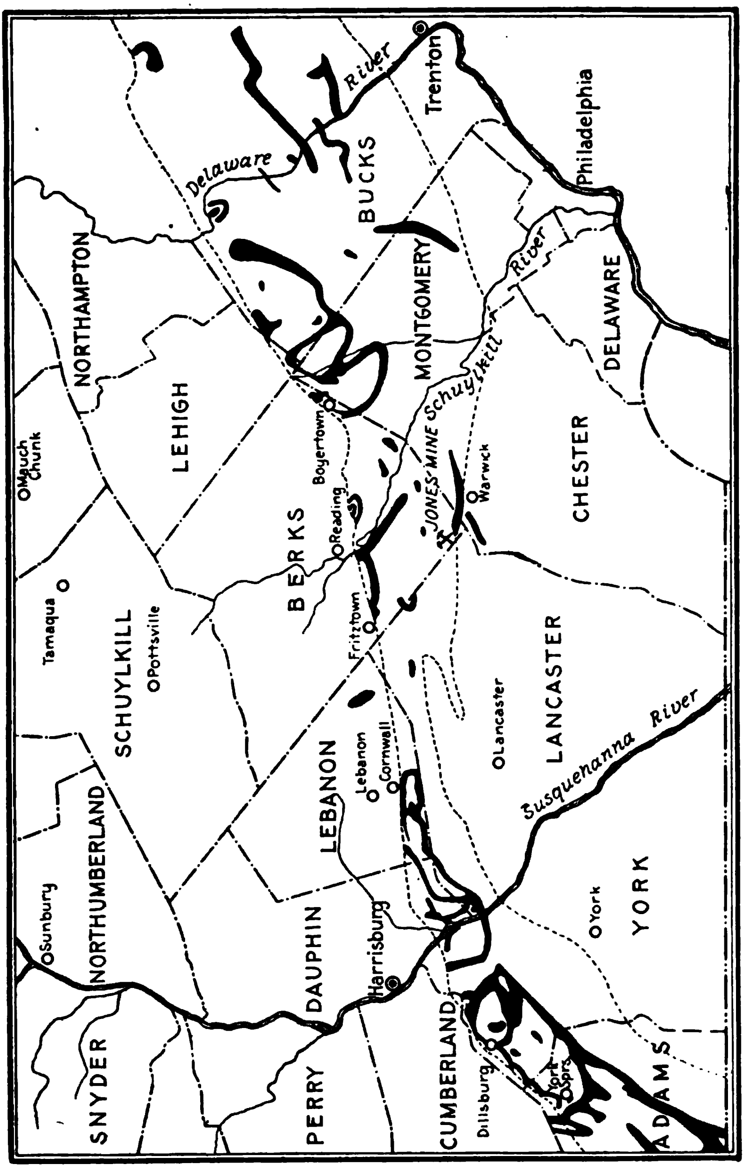

Fig. 44.—Map of Pennsylvania magnetite region. (Spencer.)

STEWART, C. A. The Magnetite Belts of Putnam County, N. Y. *School of Mines Quarterly*, April, 1908.
STOLTZ, G. C. The Forest of Dean Iron Mine (Orange County, N. Y.). *Eng. and Mining Journal*, May 20, 1908.

MAGNETITES OF SOUTHEASTERN PENNSYLVANIA

The belt of pre-Cambrian rocks, noticed under the last heading, continues across southeastern Pennsylvania, and there also contains a number of workable magnetite deposits. The most important of the Pennsylvania magnetites, however, though occurring in the same general section of the state are entirely

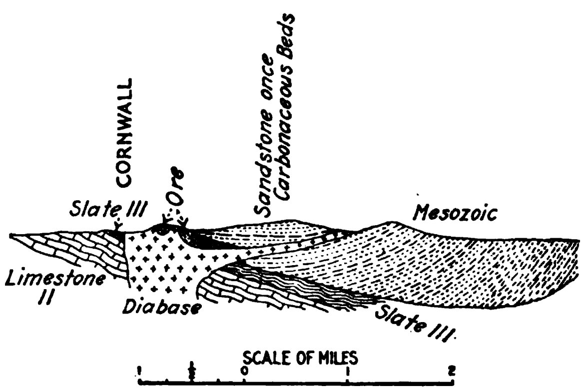

FIG. 45.—Cross-section of Cornwall ore-body. (Spencer.)

different from these pre-Cambrian ores in their origin, geologic associations and characters. They are magnetite deposits of Triassic age, formed by contact action along the borders of the great masses of basic igneous rocks which appeared during this period.

By far the most important Pennsylvania magnetite bodies is Cornwall, which is typical of the class just mentioned.

The following publications refer to the magnetites and hematites of southeastern Pennsylvania.

HARDER, E. C. Structure and Origin of the Magnetite Deposits near Dillsburg, York Co., Pa. *Economic Geology*, vol. 5, pp. 599–622. 1910.
SPENCER, A. C. Magentite Deposits in Berks and Lebanon Counties, Pa. Bulletin 315, U. S. Geol. Survey, pp. 185–189. 1907.
SPENCER, A. C. Magnetite Deposits of the Cornwall Type in Pennsylvania. Bulletin 359, U. S. Geol. Survey, pp. 102 . 1908.

CLINTON RED ORES OF NEW YORK AND PENNSYLVANIA

Bedded red hematites of Clinton age occur underlying large areas in New York and Pennsylvania. As in the case of the southern Clinton ores, these are in part oolitic, in part replacements of fossil fragments, in part merely fillings of iron oxide between sand grains and pebbles. They have been worked extensively in Pennsylvania in the past, and to a considerable extent in New York. During recent years there has been little opportunity for much development of ores of this type, but it is probable that in the near future more interest will be shown along this line. Though their grade is only fair, the reserves are of very large tonnage and easily determined and located.

The following reports and papers refer to the Clinton ores of New York and Pennsylvania.

ECKEL, E. C. The Clinton Hematite in New York. *Eng. and Mining Journal*, vol. 79, pp. 897–898. 1905.

HIGGINS, E. Stripping Clinton Ores in New York State. *Eng. and Mining Journal*, Dec. 12, 1908.

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NEWLAND, D. H., and HARTNAGEL, C A. Iron Ores of the Clinton Formation in New York State. Bulletin 123, N. Y. State Museum, 1908.

RUTLEDGE, J. J. Clinton Iron Ores of Stones Valley, Huntingdon Co., Pa. Trans. Amer. Inst. Min. Engrs., vol. 39, 1908.

BROWN ORES OF THE NORTHEASTERN STATES

Brown ores occur in western New England, southeastern New York, northern New Jersey and southeastern Pennsylvania. They were mined extensively in the early days of the iron industry, but fell into disuse as charcoal disappeared and better ores came in from the Lake and other regions. At present one mine in New Jersey and a few in Pennsylvania are still operated in ordinary years.

So far as future industrial importance is concerned, the northern brown ores do not offer much prospect of further development. The heavy covering of glacial drift makes both prospecting and mining much more expensive than in dealing with ores of similar type in the south.

The following publications refer to the brown ores of the northeastern states.

Bayley, W. S. Iron Mines and Iron Mining in New Jersey. Vol. 8, Reports New Jersey Geol. Survey. 1910.

Eckel, E. C. Limonite Deposits of Eastern New York and Western New England. Bulletin 260, U. S. Geol. Survey, pp. 335–342. 1905.

Hobbs, W. H. Iron Ores of the Salisbury District of Connecticut, New York and Massachusetts. Economic Geology, vol. 2, pp. 153–181. 1907.

Hopkins, T. C. Cambro-Solurian Limonite Ores of Pennsylvania. Bulletin Geol. Society America, vol. 2, pp. 475-502. 1900.

RED HEMATITES OF THE WESTERN ADIRONDACKS

A series of deposits of red hematite occurs along the western flank of the Adirondack region, in St. Lawrence and Jefferson counties, New York. Some of these deposits have been worked, at intervals, for eighty years or so; one or two of them are still operated during prosperous years. Comparatively little attention has been paid to exploration in this region, and it is possible that the reserves here are of more importance than is commonly assumed. The developed tonnage is, of course, very small.

The ores are red hematites of moderate grade, ranging commonly from 40 to 50 percent metallic iron as shipped, and averaging probably a little below 45 percent. The following analyses, quoted from the Tenth Census report, are as useful as any later results and show the general range more completely.

ANALYSIS OF RED HEMATITES, WESTERN ADIRONDACKS

Metallic iron.	40.40	46.32	41.92	42.18	48.36	36.78	54.16	46.46	44.35
Phosphorus	0.204	0.285	0.130	1.138	0.115	0.212	0.156	0.214	0.226

CARBONATE ORES OF OHIO AND WESTERN PENNSYLVANIA

Associated with the Carboniferous rocks of western Pennsylvania and Ohio are bedded deposits of iron carbonate ores. These were formerly worked on a considerable scale, but with the opening up of the Lake ranges the use of the local carbonates fell off. There is still, however, a small but regular production of carbonate ore reported from eastern and southeastern Ohio.

The ores are commonly spoken of as carbonates, and in fact they were such in their original form. But atmospheric and sub-surface weathering has altered much of the ore to brown ore at and near the outcrop. All of the ore now mined is calcined before use in the blast furnace.

Analyses of typical Ohio ores, after being calcined, are as follows:

ANALYSES OF CALCINED CARBONATE ORES, OHIO

	1	2
Iron (Fe)	44.80	44.50
Manganese (Mn)	0.70	0.62
Sulphur (S)	0.67	0.80
Phosphorus (P)	0.195	0.57
Silica (SiO_2)	18.50	23.00
Alumina (Al_2O_3)	5.75	4.45
Lime (CaO)	6.45	5.90
Magnesia (MgO)	1.95	2.55

1. "Ohio block ore." Scioto County, Ohio. Calcined ore.
2. New Castle Mine, Pine Grove, Lawrence County, Ohio. Calcined ore.

NORTHEASTERN ORE REQUIREMENTS

Having discussed the known ore deposits of the northeastern states, it will be serviceable to consider how far these local reserves are utilized at present, and what the prospects are for greater development in the future.

Present Ore Production.—For a number of years past the northeastern district has normally produced between two and three million tons of ore per annum, the only recent exception having been the year 1908 when of course the output dropped sharply. On the average, the output of the northeastern states amounts to about 5 percent of the total United States production. The following summary table gives the figures on these points for a number of years back.

ORE OUTPUT, NORTHEASTERN STATES, 1905–1912

Year	Iron ore putput, northeastern states, tons	Ore putput, total United States, tons	Percentage, northeast
1905	2,520,845	42,526,133	5.93
1906	2,582,666	47,749,728	5.41
1907	2,823,422	51,720,619	5.46
1908	1,590,098	35,924,771	4.42
1909	2,280,741	51,155,437	4.46
1910	2,605,318	56,889,734	4.58
1911	2,098,923	43,876,552	4.79
1912	2,139,058	55,150,147	3.88
1913	....	....	....
1914	....	....	....

Chief Sources of Supply.—The total ore produced in the northeastern states comes chiefly from three main sources of supply. Almost half of the total usually comes from magnetite mines in the Adirondack region of New York; and almost a quarter of the total each from northern New Jersey and southeastern Pennsylvania. Of the small balance, Ohio carbonate ore, red hematite from the western Adirondacks, and brown ores from eastern Pennsylvania account for all but a few thousand tons.

The distribution of the magnetite ore which makes up almost all of the northeastern total, by states is shown in the following table, for the years 1910–1912 inclusive.

CHIEF SOURCES OF MAGNETITE OUTPUT, 1910–1912

Tons of Magnetite Produced

	1910	1911	1912
New York	1,222,471	1,029,231	1,110,345
Pennsylvania	632,409	477,908	476,153
New Jersey	521,832	464,052	364,673

Present Ore Markets.—The present distribution and markets for northeastern iron ores may be summarized as follows. Of the Adirondack ores, a portion is used in local furnaces, at Standish and Port Henry; a small fraction commonly goes to furnaces in the Buffalo district; and the remainder, which is over half the total, is shipped by rail to furnaces in eastern Pennsylvania. The ores from northern New Jersey are used locally, in furnaces situated in northern New Jersey and eastern Pennsylvania. The Cornwall and other eastern Pennsylvania ores are used locally, in furnaces quite near the mines.

It will be seen that, except for such tonnage as reaches the Buffalo region, all of the northeastern ore is at present used in furnaces situated in the same general region. As to ownership of the ore, it is probably safe to say that considerably over half of the ore now mined each year in the northeastern states goes to furnaces interested directly in the mines. The total amount of merchant ore, reaching the general ore market, may range from 500,000 tons to 1,000,000 tons per year. As to competition, the northeastern ores meet foreign ores in New Jersey and Pennsylvania markets; and meet Lake Superior ores at Buffalo and in eastern Pennsylvania.

Prospects for Future Development.—We may assume, without chance of serious error, that at present some three or four hundred

million tons of commercial concentrates could be turned out from magnetite ore-bodies which have been well developed and proven up in the northeastern United States. It is probable that at least an equal tonnage could be made from deposits known to exist, but not yet sufficiently developed to warrant close estimates. All this is ore which could be mined, milled and sold at a profit under the conditions which exist to-day. It does not take into consideration the enormous tonnages of Clinton ores and other possible future sources of supply.

As against these reserves which are measured in hundreds of millions of tons, we face the fact that the annual ore output in the northeastern states is some two or three million tons a year; and that it is not growing, on the average. The question at issue is whether there is any reason to expect developments which will increase the market for these ores, and permit larger annual output.

This question may, in my opinion, be answered in the affirmative. There seem to be several causes at work which will, in the near future, create a better demand for at least some of the northeastern ores. Primarily, there is the growth of iron and steel manufacture in the eastern district; which the recent tariff changes, after a temporary discouragement, will doubtless be found to help rather than hinder. Second, as affecting competitive values, we have to consider that the completion of the New York State canals will permit cheaper transportation of Adirondack ores to their markets.

CHAPTER XX

THE WESTERN UNITED STATES

The Western District, as that term is here used, includes the eleven states lying west of the eastern lines of Montana, Wyoming, Colorado and New Mexico. It thus comprises somewhat over a third of the total area of the United States. On the other hand, it produces somewhat less than 2 percent of the total output of iron ore in the United States.

Productive Status of the West.—The present situation in this regard is well brought out by the following table.

IRON-ORE PRODUCTION OF WESTERN DISTRICT, 1906-1912

Year..........	1906	1907	1908	1909	1910	1911	1912
Production, tons.	806,268	831,258	528,625	637,582	861,850	746,971	815,425
Percentage of United States.	1.69	1.61	1.47	1.25	1.51	1.70	1.47

The preceding figures are taken from reports of the United States Geological Survey. For the earlier years they include all iron ore mined in the west, not only that used for pig iron but also the tonnage used as flux at plants smelting other metals.

Practically all of the tonnage given in the above table now comes from the Hartville region of Wyoming, and goes to the only important western furnace plant, that of the Colorado Fuel and Iron Co., at Pueblo, Colorado. There is a small electric furnace operating in California, and at different times more or less serious attempts have been made to make iron and steel in Oregon and Washington. The Colorado plant, however, is the only large and steadily operated consumer of iron ore in the entire western district, and this condition is not likely to be changed in the near future. A high tariff might ultimately induce the manufacture of iron and steel at another interior point, such as Ogden, as well as at some coast point. But the market is not large at the best, and under existing conditions it can be supplied more cheaply from outside sources.

Hartville Region, Wyoming.—The Hartville iron region is located in eastern Wyoming, in Laramie County. As at present developed, it is a relatively small area, not over 20 or 30 square miles being involved. Shipments from this region commenced in 1868, and since that date it has become the principal source of supply for the furnaces of the Colorado Fuel and Iron Company at Pueblo.

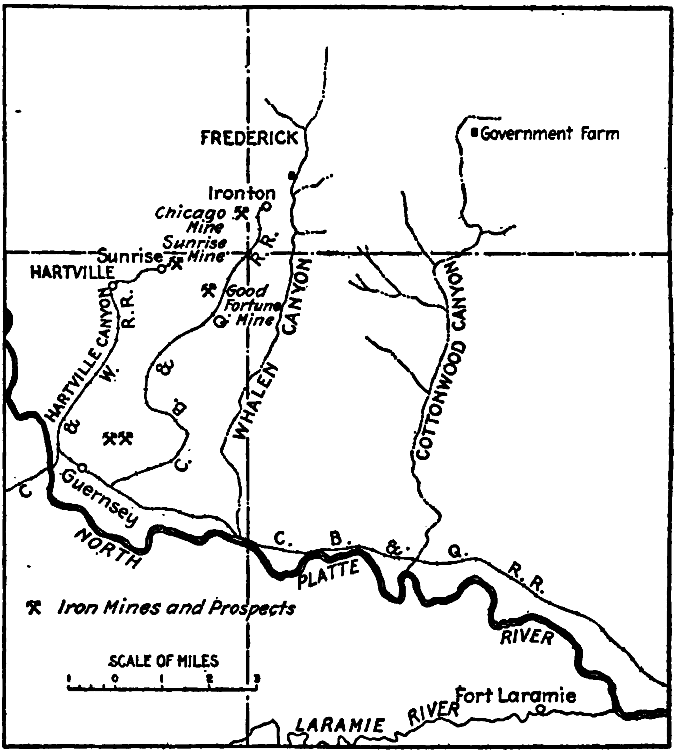

FIG. 46.—Map of Hartville district, Wyoming. (Ball.)

In the Hartville region steeply dipping pre-Cambrian rocks are overlain and encircled by flat-lying rocks of Carboniferous and later age. The iron deposits occur in the pre-Cambrian series, and the later rocks are of interest chiefly as offering difficulties to prospecting and development.

The pre-Cambrian rocks of the area include schists, limestones, quartzites and igneous rocks. The ores occur as lenticular

deposits replacing certain of the schist lenses, and also as fillings along faults. Contact deposits also occur; but the main ores are the lenticular masses first mentioned. These have undoubtedly originated by replacement, and the only point at issue is the orig-

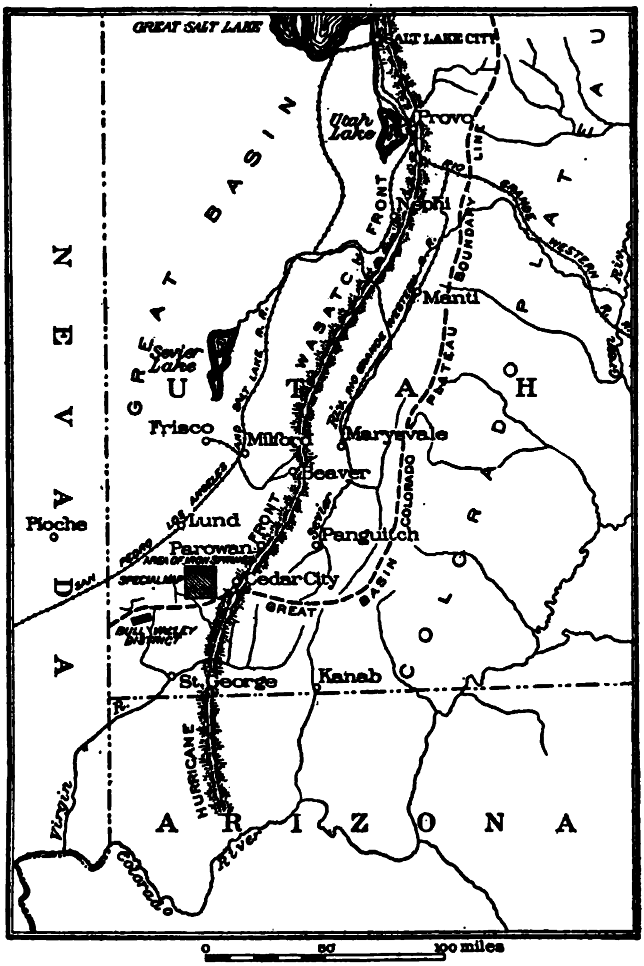

FIG. 47.—Map of Iron Springs district, Utah. (Leith and Harder.)

inal source of the iron. Ball and Leith are inclined to consider that the schist was originally a fairly ferruginous material, and that the process has been one of secondary concentration within the original bed, as in the Lake Superior region. The descrip-

tions given, however, do not seem to be conclusive on this point.

The ores are hematites, in places soft and partly hydrated, in other places hard. Sulphur is low, but phosphorus is up to or above the Bessemer limit. The ores grade from 45 to 65 percent or over in metallic iron, and the average shipments are in the neighborhood of 55 percent.

Iron Springs Region, Utah.—The Iron Springs district is located in southwestern Utah, in Iron County. Its ores have been known for forty years or more, but absence of demand and difficulties of transportation have prevented active development. It is possible that in the near future western growth may justify their utilization, at some assembling point such as Ogden, where coking coal can be brought to meet them.

The ore deposits occur along and near the contact between limestone and igneous rocks. Several large andesite laccoliths appear as peaks rising above the Carboniferous and Cretaceous rocks through which the igneous rocks have been forced. The sedimentary rocks are altered near the contact, and where the andesite is in immediate contact with Carboniferous limestones deposits of iron ore have replaced the limestone. There are also ore deposits, of minor importance, in the andesite itself. The accompanying sections (Figs. 11, 12 and 13) from the report by Leith and Harder, will serve to exemplify the common type of occurrence and relations.

The ores of the Iron Springs region are magnetite and hematite. At and near the surface the former predominates, but apparently the hematitie increases in relative proportion in depth. The range in metallic iron is from 45 to 69 percent; phosphorus is variable but averages slightly above the Bessemer limit; sulphur is still more variable and may increase in depth. Leith gives the following as the average of all obtainable analyses of ores from this region:

Metallic iron	56.0
Manganese	0.196
Copper	0.027
Phosphorus	0.200
Sulphur	0.057
Silica	7.0
Alumina	1.0
Lime and magnesia	4.0
Soda and potash	2.0
Water	3.0

Colorado and New Mexico Ores.—At various points in Colorado and New Mexico iron ores have been mined, both for the Pueblo furnaces and for smelter flux. These ores have mostly been gossan or contact deposits, and none are of sufficient present

Fig. 48.—Map of southern California iron districts. (Harder.)

or future importance to justify separate description. The Fierro deposits in New Mexico may be mentioned as an important source of supply, some years ago, for the Pueblo furnaces.

Pacific Coast Iron Ores.—In the Sierra Nevada, as well as in other portions of the three Pacific Coast states, iron-ore deposits

of more or less importance have been located and described. Those at Minaret, Madera County, California and in the Eagle Mountains, Riverside County, are said to be of large tonnage, perhaps fifty to one hundred million tons each. Deposits in Shasta County are worked for the electric furnace on the Pitt River; and ores in Oregon and Washington have been slightly developed in connection with various attempts at iron manufacture in those states. But the fuel and labor conditions on the Pacific Coast are not as attractive as the ores, and there is little reason to expect any active development in the near future.

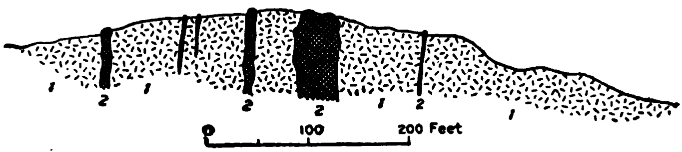

FIG. 49.—Sketch showing iron ore deposits near Dale, California. (Harder.)

The Western Ore Situation.—The western district, as here defined, comprises about one-third of the total area of the United States. On the other hand, whatever basis we may adopt in estimating our ore-reserves, it would be difficult to credit the western district with containing more than one-tenth of one-fifteenth of the total known iron ores of the United States. It will be seen that there is a vast disparity between area and known tonnage, and that we must be dealing with a region which either has not been carefully prospected for iron, or which was originally less rich in iron ores than other portions of the country. It is probable that both of these conditions exist, and that there are large gaps in our knowledge as well as some original deficiency in ores.

As regards the first point, there has been so little demand for iron ore in the western states that there has been no special inducement either to search for it carefully, or to report any occurrence which is found accidentally. It is probable enough that, should the demand ever become serious, careful prospecting would develop much larger tonnages of iron ore in the western states than are now known to exist in that region. On the other hand, deficiencies in present knowledge do not seem to account entirely for the conditions met. Iron ores, to be of commercial

value at all, must occur in relatively large deposits, and we must come to the conclusion that certain types of iron deposit, well-known elsewhere, are not abundant in the west or they would have been recognized before now.

Anyone taking up the literature relating to iron-ore deposits in the Rocky Mountain and Pacific States will be struck at once by the stress laid upon deposits due, either directly or indirectly, to igneous action, as compared with the relative unimportance of such types of iron deposits elsewhere in the United States. To some extent this condition might be attributed to the fact that most of the geologists who have described western iron ores have been predisposed, by their experience with other metallic ores, to give much attention to those modes of origin. But there is reason to believe that ore deposits of the igneous or contact types are, actually and necessarily, relatively more common in the western than in the eastern portion of the country.

Certain types, which furnish the bulk of the eastern reserves, do not appear to occur in the west, or else they are of less relative importance. So far as known, for example, the western geologic series does not contain any workable beds of purely sedimentary ores, like the well-known Clinton hematites of our eastern and southern states and the minette ores of the Lorraine-Luxembourg region. Our common type of Appalachian brown-ore deposit seems also to be relatively rare in the west, and there are so few western areas where the necessary geologic, topographic and climatic conditions have existed during recent periods as to offer little hope of finding such deposits heavily represented. On the other hand, we do find in the western region heavy magnetite and hematite replacements along igneous contacts, brown-ore deposits originating from decomposing sulphides, and in one area replacement deposits closely similar to the Lake Superior type.

Publications on Western Iron Ores.—The following list contains titles of most of the reports and papers dealing with iron ores in the Rocky Mountain and Pacific States. For convenience of reference they are arranged by states, in alphabetical order.

Arizona

UPHAM, W. E. Specular Hematite Deposits, Planet, Arizona. *Mining and Scientific Press*, April 15, 1911, pp. 521–523.

California

AUBURY, L. E. Iron Ores of California. Bulletin 38, Calif. State Mining Bureau, pp. 297–305. 1906.
DILLER, J. S. Iron Ores of the Redding Quadrangle, Cal. Bulletin 213, U. S. Geol. Survey, pp. 219–220. 1903.
HARDER, E. C. and RICH, J. L. Iron-ore Deposit near Dale, San Bernardino Co. Bulletin 430, U. S. Geol. Survey, pp. 228–239. 1910.
JONES, C. C. An Iron-ore Deposit in the California Desert Region. *Eng. and Min. Journal.* April 17, 1909.
JONES, C. C. Iron Ores of the Southwest. *Mines and Minerals*, April, 1911.
PRESCOTT, B. Iron Ores of Shasta County. *Economic Geology*, vol. 3, pp. 465–480. 1908.

Colorado

CHAUVENET, R. Preliminary Notes on the Iron Resources of Colorado. Col. School of Mines, Report of Fieldwork and Analyses for 1886, pp. 5–16. 1888.
CHAUVENET, R. The Iron Resources of Colorado. Trans. Amer. Inst. Min. Eng., vol. 18, pp. 266–273. 1890.
DEVEREUX, W. B. Notes on Iron-ore Deposits in Pitkin County, Colorado. Trans. Amer. Inst. Min. Eng., vol. 12, pp. 638–640. 1885.
ENDLICH, F. M. Iron Carbonate of the Trinidad Region. Hayden Survey, Report for 1875, pp. 204–205. 1877.
HARDER, E. C. The Taylor Peak and White Pine Iron-ore Deposits. Bulletin 380, U. S. Geol. Survey, pp. 188–198. 1909.
LEITH, C. K. Iron Ores of Colorado. Bulletin 285, U. S. Geol. Survey, pp. 196–198. 1906.
ROLKER, C. M. Notes on Certain Iron-ore Deposits in Colorado. Trans. Amer. Inst. Min. Eng., vol. 14, pp. 266–273. 1886.
SNEDAKER, J. A. Colorado Iron-ore Deposits. *Eng. and Min. Journal.*, Feb. 16, 1905, p. 313.

New Mexico

PAIGE, S. The Hanover Iron-ore Deposits. Bulletin 380, U. S. Geol. Survey, pp. 199–214. 1909.
KEYES, C. R. Iron Deposits of the Chupadera Mesa. *Eng. and Mining Journal*, vol. 78, p. 632. 1904.

Utah

BOUTWELL, J. M. Iron Ores in the Uintah Mountains. Bulletin 225, U. S. Geol. Survey, pp. 221–228. 1904.
JENNINGS, E. P. Origin of the Magnetic Iron Ores of Iron County, Utah. Trans. Amer. Inst. Min. Engrs., vol. 35, pp. 338–342. 1904.
LEITH, C. K. Iron Ores in Southern Utah. Bulletin 225, U. S. Geol. Survey, pp. 229–237. 1904.
LEITH, C. K. and HARDER, E. C. Iron Ores of the Iron Springs District, Southern Utah. Bulletin 338, U. S. Geol. Survey, 102 pages. 1908.

LERCH, F. The Iron-ore Deposits in Southern Utah. *Iron Trade Review*, pp. 49–50. May 19, 1904.

PUTNAM, B. T. (Utah Iron Ores.) Vol. 15, Reports Tenth Census, pp. 469–505. 1886.

Washington

SHEDD, S. The Iron Ores of Washington. Vol. 1, Reports Washington Geol. Survey, pp. 215–256. 1902.

SMITH, G. O. and WILLIS, B. The Clealum Iron Ores, Washington. Trans. Amer. Inst. Min. Eng., vol. 30, pp. 356–366. 1910.

Wyoming

BALL, S. H. The Hartville Iron-ore Range, Wyoming. Bulletin 315, U. S. Geol. Survey, pp. 190–205. 1907.

BALL, S. H. Titaniferous Iron-Ore of Iron Mountain, Wyoming. Bulletin 315, U. S. Geol. Survey, pp. 206–212. 1907.

CHANCE, H. M. The Iron Mines of Hartville, Wyoming. Trans. Amer. Inst. Min. Eng., vol. 30, pp. 987–1003. 1901.

VALLET, B. W. The Iron Ores and System of Mining at Sunrise Mine.

CHAPTER XXI

NEWFOUNDLAND AND CANADA

In describing the iron ores of British America, it will be most convenient to discuss first those of Newfoundland, as being not only the most important from a reserve tonnage standpoint, but the best located so far as utilization in world commerce is concerned. The chief ore regions of the Dominon of Canada may then be taken up in turn, from east to west.

NEWFOUNDLAND

The iron ores now worked in Newfoundland possess many points of both scientific and industrial interest. They are sedimentary ores, of a higher grade in iron than most other ores of that origin; the total tonnage present makes up one of the very largest and by far the most compact ore reserves in the world; and the bulk of this tonnage is submarine. At present most of the ore is mined several miles from land, under an arm of the ocean; in spite of which fact the ore can be placed in any Atlantic port of America or Europe at a cost far lower, per unit of iron, than any competitive ore. Under these circumstances, which in the long run must give Newfoundland a high rank as a source of iron ore, it will be worth while describing the deposits and the general situation in considerable detail.

Geologic Features.—Iron ores occur at many points in Newfoundland, but the only deposits now worked are those in Conception Bay, in southeastern Newfoundland, some 15 miles west of St. Johns. The deposits in question are sedimentary beds, occurring interstratified with sandstones and shales. The associated rocks are of Cambrian and Ordovician age, and iron-ore beds occur in both series, but the main workable beds are confined to the upper or Ordovician portion of the series.

The shores of Conception Bay are, for the most part, made up of slates and other rocks of pre-Cambrian age. At intervals, however, little outliers of Cambrian shales and limestones are

seen along the immediate coast. These outlying bodies dip in all cases toward the bay, and indicate that the bay is underlain by a basin or trough of Cambrian and later rocks. Actual working has demonstrated the truth of this theory.

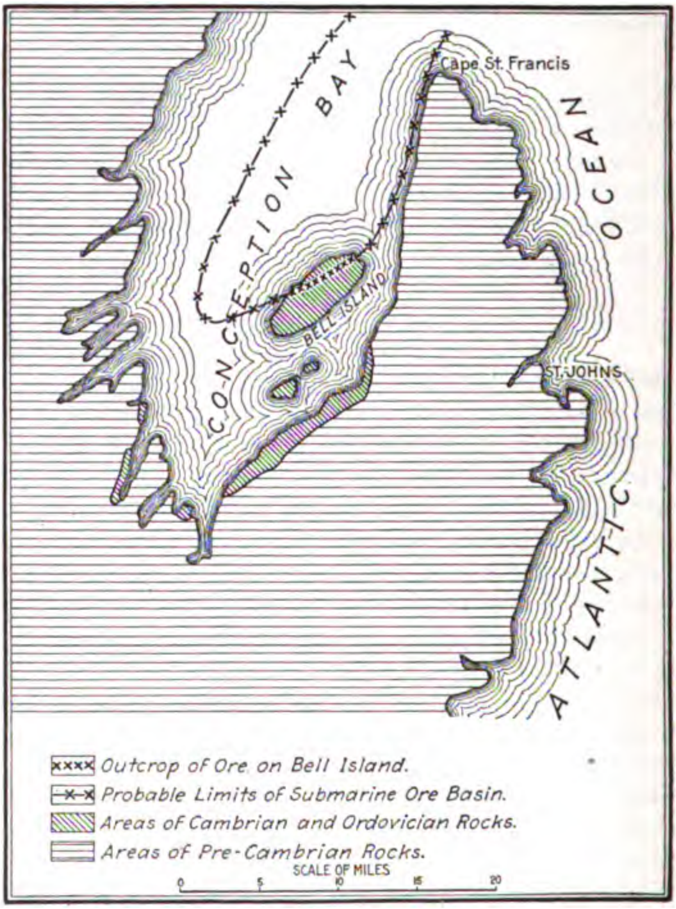

FIG. 50.—Map of Wabana ore basin, Newfoundland.

It has been noted that the ore beds are confined, so far as now known, to the upper portion of the series. The ore-bearing portion outcrops on Bell Island, an islet some 2 miles wide and 6 miles long, lying several miles off-shore in the bay. Iron mining was first commenced on the outcrop on Bell Island, and

its prosecution in the submarine areas took place at a considerably later date.

The Main Ore Beds.—Disregarding the seven or eight ore beds which are present, but too thin to be workable, the ore reserves of this field are contained in three beds. These, named from top downward, are respectively called the Little Upper, the Scotia and the Dominion Seams. The names assigned do not imply anything as to the actual present ownership by the two steel companies now mining the ores. All three of these beds are worked in the land areas on Bell Island; while the submarine slopes of the Scotia company operate at present in the Dominion Seam only.

Of the three beds worked, the topmost or Little Upper bed ranges in workable thickness from 5 to 8 feet, and averages about 6 feet. Sixty feet below it, the interval being filled with shales and thin sandstones, comes the Scotia bed. This is about 8 feet thick at all portions of its exposure. Below the Scotia bed come about 350 feet of shales again, between it and the Dominion bed. This last ranges from 12 to 20 feet in thickness ordinarily, though in one portion of the submarine workings a thickness of 33 feet was measured. Taken throughout the entire explored area, the Dominion bed will probably give an average workable thickness of close to 16 feet.

Grade and Composition of Ore.—The ores of the Wabana basin are dense, fine-grained red hematities, ranging from 48 to 57 percent in metallic iron, with 6 to 12 percent silica. The three beds differ somewhat in grade of ore, though the differences are not great, the Scotia bed showing the highest iron content.

The Dominion bed, from which practically all of the shipments are now made, will yield an average of 48 to 50 percent metallic iron, if shipped as mined. At the mines of the Nova Scotia Steel Co., however, the installation of a picking belt has brought the average grade up to 51 or 52 percent iron, at slight additional cost. For the years 1910 to 1912, inclusive, the total shipments of this company averaged 51.88 percent iron and 9.56 percent silica. Considering the small cost of mining and transportation, it is obvious that this ore can be placed in any Atlantic coast market, whether in Europe or America, at a lower cost per unit of iron than any known competitive ore.

The phosphorus ranges from 0.70 to 0.85 percent, which with

the ore grade as it is, produced a pig metal carrying 1.4 to 1.7 percent phosphorus. If used alone, the ore would therefore make a pig too high in phosphorus for normal economic basic open-hearth practice; but suitable for foundry use or for one of the modified processes which have been developed in Europe. With the addition of either low or high phosphorus ores, however, mixtures can be cheaply produced for making basic open-hearth or basic Bessemer pig.

As to other ingredients, a typical complete analysis published by Cantley shows sulphur 0.018 percent, lime 1.80 percent, manganese 0.65 percent and alumina 3.55 percent.

The Wabana ore, as has been noted, is a very dense material. For the following determinations of the specific gravity of average samples from the three main beds I am indebted to Mr. E. E. Ellis.

	Sp. grav.
Little Upper bed	3.99
Scotia bed	3.95
Dominion bed	4.12

It will be noticed that here as elsewhere the richest ore is not necessarily the highest in specific gravity, for the pore space in the ores from the Upper and Scotia beds more than counterbalances their higher iron content.

Market Points.—Located as they are, on deep water, the Wabana ores have a very extensive possible market area. The following table, taken from a recent paper by Mr. Cantley, gives details regarding steaming distances from Wabana to various ports in Europe and America:

DISTANCES FROM WABANA TO MARKET PORTS

Stettin	2633	Baltimore	1398
Emden	2475	Philadelphia	1242
Amsterdam	2310	New York	1110
Rotterdam	2294	Montreal	1065
Newcastle	2406	Quebec	930
Middlesboro	2350	Halifax	580
Liverpool	1966	Pictou	540
Glasgow	1899	Sydney	412

At present the greater portion of the tonnage from the Wabana ore field goes to the steel plants of the Nova Scotia and Dominion companies, at Sydney, Nova Scotia.

Production and Shipment.—For the following data on total exports and destinations of ore from the Wabana field during several recent fiscal years I am indebted to the Collector of the Port at St. Johns, Newfoundland.

EXPORTS AND DESTINATIONS OF WABANA ORE, 1910—1912

Destination	Year ending, July 1, 1910	1911	1912
Sydney, Canada	641,885	789,735	642,395
Philadelphia, U. S. A.	254,750	194,020	178,055
Rotterdam, Holland	105,825	122,950	104,050
Emden, Germany	....	7,400	38,330
Middlesboro, England	57,420	61,080	54,100
Total shipments	1,059,880	1,175,185	1,016,930

Both the Rotterdam and Emden shipments, of course, ultimately reach German furnaces. The following summary of the European and United States shipments, from the opening of the mines in 1895 to the end of 1912, is made up from data furnished by Messrs. Cantley and Chambers, of the Nova Scotia Steel & Coal Co. It will give the best idea of the relative importance of the three ultimate foreign markets so far as Newfoundland ore shipments are concerned.

FOREIGN SHIPMENTS 1895—1912

	Tons
Germany	2,013,269
United States	1,611,860
England	651,237
Total	4,276,366

Probable Reserve Tonnages.—The three workable beds, taken together give an average aggregate thickness of 30 feet over the entire area so far explored. As the ore is very dense, averaging about 9 cubic feet to the ton, we may assume that each square mile of ore field contains at least ninety million tons of ore. This will be used as the basis in later calculations.

As to area available, we have to deal with the facts that the three beds can be examined and measured for several miles along their outcrops on Bell Island, and that the slopes of the Scotia company are now out close to 2 miles, in a direction at right angles to the outcrop. Since the ore shows no signs of approach-

ing its termination in any of the directions seen, it is probable that even without considering any geologic argument an engineer would assume that the tonnage available is at least three thousand millions.

But as a matter of fact, the geologic argument for greater extension of this field is far stronger than may be commonly understood. On a small map (Fig. 50) the probable limits of the basin are indicated. From this it will be seen that the reserve tonnage will in all likelihood be fixed by working conditions and costs, rather than being limited by running into barren ground. If we assume that there is no technical impossibility in the way of working the ore, by slopes from the islands or the mainland, as far out as Cape St. Francis, we have to deal with a reserve aggregating some ten thousand million tons.

In view of the very serious results in case of roof defects, a heavy allowance must be made for ore left as supports. It would probably be safest to assume that the recovery will be approximately 50 percent of the total ore available. When the preceding estimates as to total ore reserves are discounted for this factor, it will be seen that even then they constitute one of the largest reserve tonnages in the world.

The following papers and reports relate to the Wabana ore basin of Newfoundland, and will serve to give further details concerning it. The paper by Cantley is of greatest general usefulness in this regard.

CANTLEY, T. The Wabana Iron Mines of the Nova Scotia Steel & Coal Co. *Journal Canadian Mining Institute*, vol. 14, June, 1911. pp. 31–56.

CHAMBERS, R. E. A Newfoundland Iron Deposit. *Journal Canadian Mining Institute*, vol. 1, p. 41. 1896.

CHAMBERS, R. E. The Sinking of the Wabana Submarine Slopes. *Journal Canadian Mining Institute*, vol. 12, pp. 141–143. 1909.

HOWLEY, J. P. The Mineral Resources of Newfoundland. *Journal Canadian Mining Institute*, vol. 12, pp. 149–162. 1909.

HOWLEY, J. P. The Iron Ores of Newfoundland. *Iron Ore Resources of the World*, 11th International Geologic Congress, vol. 2, pp. 749–752, 1910.

STEPHENSON, B. S. Mining Iron Ore at Wabana, Newfoundland. *Iron Trade Review*, Oct. 14, 1909, pp. 651–656.

DOMINION OF CANADA

The total area comprised in the Dominion of Canada is very extensive, by far the greater portion of it is practically unexplored

so far as iron possibilities are concerned, and much of it gives little promise of being able to support an iron industry even in case the ores are found. Under these circumstances an attempt to discuss the iron-ore resources of Canada in any great detail would be obviously bound to result in failure, for the scattered data which are available do not necessarily refer to the deposits of the greatest ultimate commercial importance. It seems best, therefore, to treat the subject in another fashion, and to discuss the possibilities which seem to exist in each of the industrial districts into which the area may be divided. For this purpose the following grouping seems to fit in with our present requirements:

a. New Brunswick and Nova Scotia.
b. Quebec and eastern Ontario.
c. Western Ontario.
d. Alberta and eastern British Columbia.
e. Western British Columbia.

The five areas into which Canada is divided in the above grouping do not coincide exactly with existing political divisions, but they do represent a grouping based on commercial possibilities as determined by coal supplies, population, and industrial development.

New Brunswick and Nova Scotia.—Iron-ore deposits of more or less importance occur at many points in the two provinces now under consideration. The extensive development of the Wabana ore field in Newfoundland has operated to decrease interest in the development of purely local supplies, for only a few of the known deposits seem to promise more than very local importance.

Two groups of ore deposits are now in operation, one near Bathurst, New Brunswick, and the other at Torbrook, Nova Scotia. As the ore from these mines enters to some extent into international commerce, they will be described in sufficient detail to give some idea of their present and probable future importance.

Magnetites of Bathurst Region, New Brunswick—A group of magnetite deposits occur near Bathurst, in Gloucester County, New Brunswick, and shipments have been made from them during recent years by the Canada Iron Corporation. The workings were located at Austin Brook, some 20 miles southwest of Bathurst, and the ore was shipped down a company line to Nipisiquit Junction and thence over the Intercolonial Railroad to

Newcastle. These features of the situation are brought out in Fig. 51.

The ores are moderately rich magnetites in their natural condition, grading from 40 to 46 percent metallic iron. A series of samples taken by Lindemann across various deposits gave the following results.

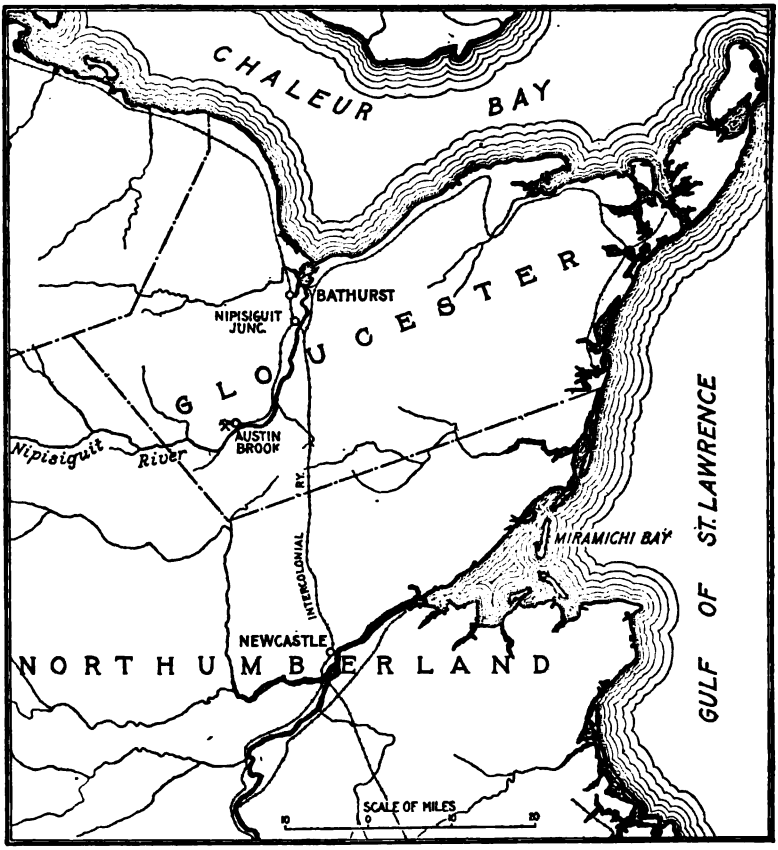

FIG. 51.—Sketch map of Bathurst district, New Brunswick.

ANALYSES OF CRUDE ORE, AUSTIN BROOK, NEW BRUNSWICK

Metallic iron	43.7	42.5	46.0	46.6	43.4	43.6	44.5	47.5
Manganese	1.0	n. d.	n. d.	1.8	n. d.	0.5	n. d.	1.2
Insouble matter..	26.3	34.6	21.6	24.7	25.2	33.1	28.5	22.7
Phosphorus.....	0.64	1.20	1.21	1.04	0.82	0.40	0.83	0.65
Sulphur.........	0.05	0.03	0.05	0.02	0.02	0.007	0.03	0.05

The ores occur as long lenses enclosed in schist. This schist is supposed by the Canadian geologists to be a mashed porphyry of Silurian or later age. A diabase body of still later age occurs near the main ore lens, but is not known to be in contact with it at any point. Fig. 52 is a sketch, made up from my own observations and the records, and shows the main ore mass as it originally outcropped, and brings out this feature of the matter.

The ore mass now worked is about 2000 feet in length, trending about N. 10° E-, and dipping westward. Near the outcrop the dip was 65 degrees, but this flattened toward the south end of the lens. From wall to wall the lens gave a total width of 110 feet at the outcrop, narrowing southward. The walls on both sides are schist, and there are inclusions and stringers of a greenish chloritic schist, which at one point forms a horse of considerable size.

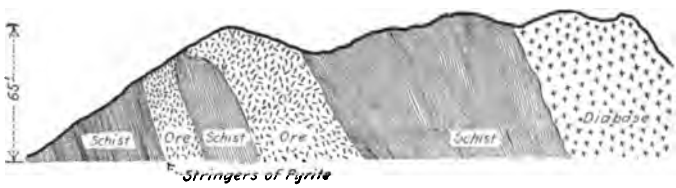

Fig. 52.—Cross-section of ore-body at Austin Brook, New Brunswick.

The crude ore as mined gave 42 to 43 percent iron; this was concentrated wet to a product carrying 48 to 49 percent iron. All the mining done so far has been open cut; but in a short time underground work will have to be taken up in order to avoid too heavy stripping.

Hematities of the Torbrook Region, Nova Scotia.—At various points in Nova Scotia the Clinton and other Paleozoic rocks carry ores similar in origin and general character to those mined so extensively in the Birmingham region of the United States. In past years these ores have been worked, on a relatively small scale, in different portions of the province; but at present the ores of the Torbrook district are the only sedimentary ores being mined in Nova Scotia.

The Torbrook mines are located in Annapolis County, about 5 miles southeast of the station of Middleton, which is a junction point for the Dominion Atlantic and the Halifax Southwestern railroads. The mines are connected with both roads

by spur tracks. During recent operations most or all of the shipments have been down the Halifax Southwestern to Port Wade, where loading docks permit access of ocean-going steamers. The total rail haul by this route is some 45 miles from mine to dock.

In the vicinity of Torbrook the Devonian series contains several ore beds, and folding brings these to the surface in two belts of outcrops. These conditions result in a number of exposures of the ore, and in a general impression that the field is more important than is really the case. When carefully examined, it is found that only two beds are workable; and that though the total tonnage existing is unquestionably large, there are some difficulties connected with the matter.

In the developed portion of the field the two workable beds—the Shell and Leckie beds—are steeply inclined, dipping about 80 degrees to the southeast, the trend of the outcrop being North 40 East. The beds vary considerably in thickness from point to point, but average about 5 feet thick each. They are 100 feet apart, measured horizontally across the strike. Two shafts are in operation, both beds being worked from each shaft.

The ores differ considerably in character and composition. The ore of the Leckie bed is almost a normal Clinton ore; it is a red hematite for the most part, though magnetic in places; usually massive, but oölitic at some points. The ore from the Shell bed, on the other hand, displays two features not often found in the same ore; it is very fossiliferous, and it is highly magnetic. The metamorphic effects of local igneous action have partly altered each ore bed but for some reason have had the greatest effect on the Shell ores.

The following complete analyses of the crude ore from the two beds are quoted from Woodman, so as to give some idea of the relative character of the two types of ore. They are not average analyses and are of no commercial importance.

	Shell	Shell	Leckie	Leckie
Metallic iron	45.62	47.36	54.22	50.89
Silica	10.98	9.00	11.86	14.30
Alumina	7.02	6.60	3.12	3.62
Lime	8.62	8.73	1.90	1.60
Magnesia	0.96	1.00	0.26	tr.
Phosphorus	1.105	1.115	0.90	1.17
Sulphur	0.305	0.505	0.019	n. d.

The Shell ore is always lower in iron and higher in lime than the Leckie ore. As mined, the crude ore from the two beds averages 42 to 43 percent metallic iron; this is concentrated up to 50 to 52 percent grade. One typical shipment gave 51.07 percent iron, 13.08 silica, 1.32 percent phosphorus, and 0.5 percent manganese. In this the lime would run about 3 percent, and sulphur about 0.015 percent.

Quebec and Eastern Ontario.—Scattered over the Province of Quebec, and the eastern portion of Ontario, are deposits of hematite and magnetite. Some of these are of high-grade ore, and in some cases there seems to be reason to expect the occurrence of considerable reserve tonnage. At present most of these deposits are ruled out of the market because of transportation difficulties, and their chief interest arises from the fact that in the future they may perhaps furnish an auxiliary ore supply for the furnaces in this district built to use Lake Superior ores.

The following analyses, quoted from various reports, will serve to give some idea of the better class of ores from this area.

ANALYSES OF IRON ORES, QUEBEC AND EASTERN ONTARIO—

	1	2	3	4	5	6	7
Metallic iron	53.20	58.78	56.69	62.98	58.25	63.88	62.03
Manganese	......	tr.	......	......	......	0.15	0.15
Phosphorus	0.027	0.015	0.006	0.012	0.018	0.06	0.004
Sulphur	0.085	0.280	0.263	0.173	0.054	0.07	0.54
Silica	20.67	10.44	11.00	6.78	15.38	5.77	5.35
Alumina	0.61	......	......	......	......	......	......
Lime	......	0.76	......	......	......	0.41	0.92
Magnesia	......	0.45	......	......	......	0.17	2.41
Water	3.27	......	......	......	......	......	......

Western Ontario.—The district now to be briefly described is essentially an extension of the Lake Superior iron-ore field of the United States, and because of this fact has been explored more closely than any other Canadian area. These explorations have been disappointing so far as present results go, and Leith has pointed out that there is some geologic reason for expecting relatively small tonnages to be discovered on the Canadian side of the line. The rocks of the Canadian area are pre-Cambrian, like the Michigan and Minnesota iron-bearing series; but in Canada the Huronian rocks (which contain most of the ores of Michigan and Minnesota) cover relatively small areas; while most of the Canadian region is covered by rocks of Keewatin age, which

in the United States are of considerably less importance as containers of large ore deposits.

With this brief note on the theory of the case, we may summarize the existing status of development by saying that two producing areas or ranges have been so far discovered—the Atikokan and Michipicoten ranges—while several other more or less promising districts have been noted. The Michipicoten range has only one producing mine—the Helen—while the Atikokan range does not appear to be very extensive. The Atikokan ores are shipped to the furnaces at Port Arthur; while the ore from the Helen mine reaches Lake Superior by rail. The bulk is used at the Saulte, though some is shipped to eastern markets.

ANALYSES OF MICHIPICOTEN ORES, ONTARIO

Moisture—loss on drying at 212°	5.70
Metallic iron	58.20
Manganese	0.165
Phosphorus	0.127
Sulphur	0.127
Silica	4.40
Alumina	0.88
Lime	0.23
Magnesia	0.14
Loss on ignition	10.40

Average shipments from Helen Mine, 1907. Monog. LII, U. S. G. S., p. 156.

Alberta and Eastern British Columbia.—Manitoba and Saskatchewan do not give promise of becoming the seats of any important iron industry, but it is otherwise with the area immediately to the westward, for here coal supplies, iron deposits, and industrial development do offer some opportunity for the iron industry to become established on at least a moderate scale. In this connection it is well to recall that, owing to the manner in which the Rocky Mountain front range bends westward in passing up into Canada, a steel plant located at Calgary would have essentially the same location, relative to the coal fields and transportation routes, as the existing plant at Pueblo, Colorado.

Deposits of iron ore have been reported as occurring at various points both in Alberta and in eastern British Columbia, and some of the reports indicate the possibility that ore-bodies of commercial importance may exist. Nothing definite is known, however,

as to the possible tonnage or working grade of any of these deposits. But the soundness of the fuel situation in this district will make even a moderately good ore deposit available; and it may fairly be expected that further exploration will be taken up in the near future.

Western British Columbia.—An important series of magnetite deposits occur in western British Columbia. Those best known are located on Texada Island, in the Straits of Georgia, though other very promising ore-bodies are known to occur on adjoining small islands as well as on Vancouver Island.

In type all of these deposits agree quite closely. The principal ore in each case is magnetite, commonly ranging from 45 to 65 percent in metallic iron. It is often below the Bessemer limit in phosphorus; but on the other hand is almost invariably high in sulphur, to the point of requiring roasting before smelting. In many places from ½ to 2 percent of copper is contained in the ore.

As to geologic associations and origin, a general similarity is apparent among the deposits. All of the important ore-bodies, and most of the smaller ones, are located in limestone along its contact with igneous rocks. The ores replace the limestone in bodies of rather irregular form, but as no really deep-level working or exploration has been attempted, little can be said definitely as to the possible size of the individual bodies or the probable total ore reserves in the district. Different estimates have ranged from a few millions of tons up to one hundred million tons or thereabout, as the total reserve.

Comparatively small shipments of these ores have been made in the past to furnaces in the states of Washington and Oregon; but the failure to establish a sound iron industry on the Pacific Coast has prevented any great development of the ores. The proximity of the Vancouver Island and other British Columbia coal fields indicates that their final use will probably be in the province itself, though up to the present day it has been assumed that a sufficient market is not available to justify the erection of even a small furnace. The real limitation, however, is the low cost at which Chinese and Indian pig iron can be placed on this coast. Local labor costs are also high, which may prevent development in the near future.

Status of Iron Production in Canada.—The first recorded discovery of iron ore in Canada was in 1667, and as early as 1730

at least one forge was in operation. This earliest plant was succeeded, in 1737, by a group of forges at Three Rivers, Quebec, which remained in active operation until 1883, being at that date the oldest active iron producers on the American continent. Other plants were put in operation during the eighteenth and early part of the nineteenth century, most of the ore used being either bog ore or the magnetic iron sand occurring along the St. Lawrence River. In 1873 an attempt was made to produce steel directly from these sands in an open-hearth furnace, but the product was irregular in grade and the total quantity small.

The existing iron and steel industry of Canada shows little relation, either in location or in raw materials, to these earlier plants. With the exception of a relatively small production in Quebec from local ores, the iron industry of the Dominion may be said to have developed in three directions; first, an important group of producers located in Nova Scotia, and using ores from that province, from New Brunswick and from Newfoundland; second, another group located in Ontario, at Hamilton, Deseronto and Midland, using ores mostly from the American and Canadian Lake Superior fields; and third, two companies located respectively at Sault Ste. Marie and Port Arthur, Ontario, and also using Lake ores.

The following data on pig-iron production are quoted from one of the series of reports by McLeish, cited in the reference list on page 287.

PRODUCTION OF PIG IRON IN CANADA, 1887–1910

Year	Ontario	Nova Scotia	Quebec	Total
1887	......	19,320	5,507	24,827
1890	......	18,382	3,390	21,772
1895	......	35,192	7,262	42,454
1896	28,302	32,351	6,615	67,268
1900	62,387	28,133	6,055	96,575
1905	256,704	261,014	7,588	525,306
1910	447,273	350,287	3,237	800,797

It may be added that in 1910 the steel production of Canada amounted to 822,284 tons of ingots and castings, which produced 739,811 tons of rolled products. Of this last total rails accounted for 366,465 tons, or almost half of the entire quantity of rolled products.

Recurring now to the question of ore development, which might be assumed to have accompanied this growth in finished

products, it may be said that of some one and one-half million tons of ore used in 1910 in Canadian furnaces, less than 200,000 tons were mined in Canada itself. Of the remainder, some 800,000 tons were mined in Newfoundland, while 500,000 tons or more came from the American Lake ranges. The chief Canadian ore producers at present are the Helen, Atikokan, Moose Mountain and Mayo mines in Ontario; the Bathurst deposits in New Brunswick; and the Torbrook mines in Nova Scotia. All of these together are of course overshadowed by the Wabana mines in Newfoundland.

Reference List on Canadian Iron Ores.—The following list contains titles of a number of the more important recent reports and papers dealing with the geology or development of iron ores in Canada. It is of course far from complete, but the papers cited will serve to indicate where further data may be found.

Coleman, A. P. The Helen Mine, Michipicoten. Economic Geology, vol. 1, pp. 521–529. 1906.

Cirkel, F. Iron-ore Deposits along the Quebec and Gatineau Rivers. Report Canadian Dept. Mines, 147 pp. 1909.

Dawson, G. M. Report on a Geological Examination of the Northern Part of Vancouver Island and Adjacent Coasts. Canadian Geol. Survey, Report for 1886, part B, pp. 1–129. 1887.

Frechette, H. Torbrook Iron-ore Deposits, Nova Scotia. Bulletin 7, Canadian Dept. Mines, 13 pp. 1912.

Haanel, E. The Iron Ores of Canada. *Iron Ore Resources of the World*, vol. 2, pp. 721–743. 1910.

Hille, F. Iron-ore Deposits in Thunder Bay and Rainy River Districts, Ontario. Report Canadian Dept. Mines, 65 pp. 1908.

Leith, C. K. Iron Ores of the Western United States and British Columbia. Bulletin 285, U. S. Geol. Survey, pp. 194–200. 1906.

Leith, C. K. Iron Ores of Canada. Economic Geology, vol. 3, pp. 276–291. 1908.

Lindeman, E. Iron-ore Deposits of Vancouver and Texada Islands. Report Canadian Dept. Mines. 1909.

Lindeman, E. Iron-ore Deposits of the Bristol Mine, Pontiac County, Quebec. Bulletin 2, Canadian Dept. Mines. 1910.

McLeish, J. The Production of Iron and Steel in Canada during 1907 . . . (and subsequent years). Annual publication of Canadian Dept. Mines. 1908–date.

Richardson, J. Report on Geological Explorations in British Columbia. Canadian Geol. Survey, Report for 1873–1874, pp. 94–102, 260. 1874.

Van Hise, C. R. and Leith, C. K. The Geology of the Lake Superior Region. Monograph LII, U. S. Geol. Survey. 1911.

Woodman, J. E. Report on the Iron-ore Deposits of Nova Scotia. Report Canadian Dept. Mines, 226 p. 1909.

CHAPTER XXII

THE WEST INDIES, MEXICO AND CENTRAL AMERICA

In the present chapter are combined, purely as a matter of convenience, the discussions of the iron-ore resources of the West Indies, of Mexico, and of Central America. The group thus made is heterogeneous politically, for it contains countries and colonies differing greatly in status. It is heterogeneous, to a scarcely less degree, from the geological standpoint, for it includes areas differing greatly in geological history and formations. Finally, from the standpoint of iron ore production or possibilities, it includes certain areas of great international importance, other areas which give some promise of future importance, and still others which will probably never become serious producers of either iron or iron ore.

Cuba, for example, is known to contain one of the largest ore reserves in the world; Hayti and Porto Rico are promising, but relatively unknown; while Jamaica and many of the smaller West Indian Islands can be ruled out, on purely geologic grounds, as offering little hope of ever turning up even moderate tonnages of ore. Mexico and Central America are known to contain workable deposits, but their total ore tonnage will probably be much smaller than their mere area might suggest.

CUBA

The known iron ores of Cuba fall into two groups, differing widely in character, geologic associations, tonnage and commercial importance. Those best known, as having been worked the longest, are magnetites and hematites from the south coast of the island; those of greatest ultimate importance are brown ores from the north coast. They have so little relation to each other that it will be best to describe the two types separately. In each case the principal workings are in the province formerly known as Santiago, and now as Oriente.

South-shore Hematites and Magnetites.—Since 1884 iron ores of high grade have been worked steadily in a district near

the city of Santiago, on the south coast of Cuba. The mines are located in the foothills of the Sierra Maestra, and the iron-bearing region occupies a belt reaching along the coast, within a few miles of the water. Within this general area mines have been opened as far west as Guama, 35 miles west of Santiago, and as far east as Sigua, 25 miles east of the city. The chief workings, however, have been at Sevilla, Firmeza, Daiquiri and Berraco, all located east of Santiago.

The ores are mixed magnetites and hematites, grading from

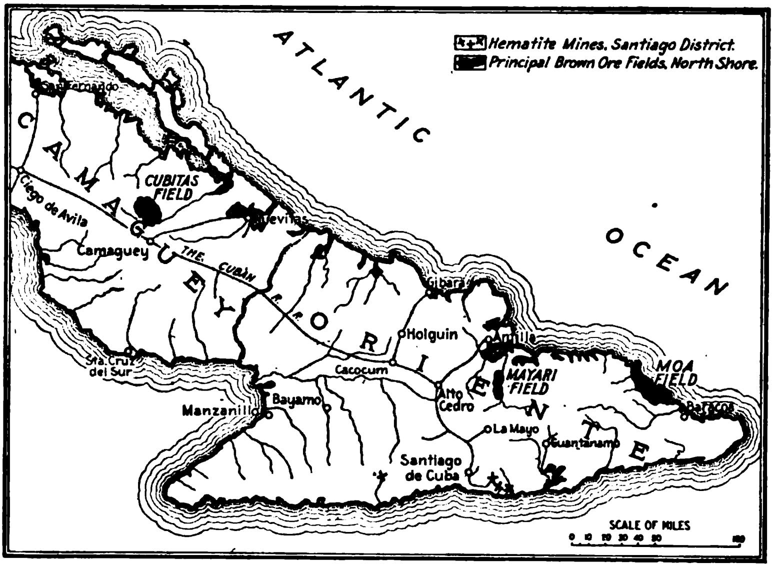

FIG. 53.—Map of eastern Cuba showing chief hematite and brown-ore deposits. (Spencer.)

55 to 65 in metallic iron, and low in both phosphorus and sulphur. Analyses of average yearly shipments from Daiquiri are quoted as follows:

	1896	1897	1906	1907
Metallic iron	63.05	63.10	57.40	57.80
Manganese	0.062	0.097	n.d.	n.d.
Phosphorus	0.025	0.029	0.038	0.034
Sulphur	0.048	0.072	0.20	0.18
Silica	7.58	7.22	11.80	10.80
Alumina	0.82	0.71	......	......
Lime	0.89	1.06	......	......
Magnesia	0.26	0.38	......	......

These ores occur in irregularly shaped deposits, associated with a series of metamorphic rocks—schists and crystalline limestones. In places these rocks are cut by igneous rocks of later date—porphyries and diorites—but Spencer does not consider that the origin of the ores is related in any way to these igneous intrusions, but that they existed as deposits in the metamorphic rocks prior to the igneous action.

The irregularity of these deposits, both as regards the shape and size of the individual ore-bodies and as regards their distribution through the mass of barren rock, is such that estimates as to reserve tonnage are to be accepted with caution. Hayes, in discussing the ore supplies tributary to the United States, credits this particular Cuban field with containing some nine million tons of ore in reserve, of which about half has been definitely placed in sight or developed by drilling.

North-shore Brown Ores.—In 1901, while examining the ore deposits of Cuba for the War Department of the United States, A. C. Spencer noted the occurrence of large deposits of brown ores near the north coast of the island, in the province of Santiago. These deposits were sampled and analyzed, but the publication of the facts in an official report aroused little interest at the time among American iron producers. Later the Pennsylvania Steel Company commenced the development of these ores, and at present the importance of the field is fully recognized.

The deposits which have so far been developed or carefully examined are in the eastern end of the island, in the provinces of Oriente (formerly Santiago) and Camaguey (formerly Puerto Principe). Brown ores which appear to be of entirely similar type have, however, been reported from other points of the island, reaching as far west as Pinar del Rio province, so that in time the working ore district may be very greatly extended beyond its present limits. Estimates of the reserve tonnage in the known deposits have been made by various geologists and engineers, and these estimates range up to some three billion tons. It is almost certain that the actual tonnage of ores of this type in Cuba will be ultimately found to be far in excess of the current estimates.

The brown ores of the north coast of Cuba are thoroughly hydrated brown hematites, carrying from 40 to 50 percent metallic iron. In their natural state the ores carry about 30 percent of moisture, in addition to the 12 to 14 percent of

combined water. As to other constituents, they are notably high in alumina, but low in phosphorus and sulphur. Their most remarkable peculiarity is the presence of considerable chromium and some nickel. All of these points in which they differ from more normal ores are explained by their origin and geologic associations. A few representative analyses may be introduced, in order to give some idea of the average grade of the ore, as shown by samples dried at 212° F.

ANALYSES OF BROWN ORES, CUBA

Metallic iron	46.03	45.18
Chromium	1.73	1.7
Nickel	n.d.	0.53
Manganese	n.d.	0.56
Phosphorus	0.015	0.1
Sulphur	n.d.	0.063
Silica	5.50	6.75
Alumina	10.33	12.3
Combined water	13.62	12.0
Moisture	31.63	

The ores are associated closely with serpentine rocks, and are thought to have been derived from these serpentines by weathering. Brown ores of similar origin were formerly worked on Staten Island, New York; and along with certain ores from Greece present the same peculiarities as to the alumina, chromium and nickel content. In the Cuban area the ores occur as a residual blanket overlying the weathered serpentine.

This blanket, in some of the more important areas, averages 15 feet in thickness, and is made up of a hard bed immediately over the serpentine, and of soft clay-like ore, with pellets and masses of harder ore, reaching to the ground surface.

It is obvious that interesting problems in both concentrating and metallurgical practice were presented by ores differing so widely from the bulk of the ores previously used in eastern furnaces. It is necessary first of all to remove the water, before shipment, so as to save freight charges which is done in rotary kilns like those used in cement manufacture. This is a rather expensive operation, particularly since the fuel required must be imported, but better technical practice will probably reduce its costs considerably.

Iron-ore Industry of Cuba.—Though the first location on the south shore hematites appears to have been filed over fifty years ago, it was not until 1884 that any serious mining operations were undertaken. In that year the Juragua Iron Company, then under the joint control of the Bethelem and Pennsylvania Steel companies, commenced mining and shipping from the mines near Seville and Firmeza. Several other companies started operations at various dates, but the only one whose work achieved permanency was the Spanish-American Iron Company, which in 1895 commenced shipments from the Daiquiri region. At that time the Spanish-American Company was an independent producer, but some ten years ago the joint control of the Juragua company was given up, it became the sole subsidiary of the Bethelem Steel Company, while the Pennsylvania Steel Company acquired control of the Spanish-American Iron Company.

When the brown ore deposits on the north coast of Cuba were discovered, both the Spanish-American and the Juragua companies took part in their.development, while several other interests also secured tonnages of more or less importance. Shipments are now being made steadily from the brown ore holdings of both companies.

The following table shows the shipments of iron ore from Cuba since the opening of the mines in 1884. The statistics of the Cuban iron-ore production were collected by the United States Geological Survey.

Reference List on Cuban Ores.—The reports and papers cited in the following list will suffice to place the more important data on the subject in form for further study. As a matter of convenience, reports dealing chiefly with the south shore hematites have been marked *A*, while those referring principally to the brown ore deposits of the north coast are marked *B*.

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SHIPMENTS OF IRON ORE FROM MINES IN THE PROVINCE OF ORIENTE (SANTIAGO), 1884–1910, IN LONG TONS

Year	Juragua Iron Co. (Limited)	Sigua Iron Co.	Spanish-American Iron Co.	Cuban Steel Ore Co.	Ponupo Manganese Co.	Total
1884	25,295	....	....	....	....	25,295
1885	80,716	....	....	....	....	80,716
1886	112,074	....	....	....	....	112,074
1887	94,240	....	....	....	....	94,240
1888	206,061	....	....	....	....	206,061
1889	260,291	....	....	....	....	260,291
1890	363,842	....	....	....	....	363,842
1891	264,262	....	....	....	....	264,262
1892	335,236	6,418	....	....	....	341,654
1893	337,155	14,020	....	....	....	351,175
1894	156,826	....	....	....	....	156,826
1895	307,503	....	74,991	....	....	382,494
1896	298,885	....	114,110	....	....	412,995
1897	*a* 248,256	....	*b* 206,029	....	....	454,285
1898	83,696	....	84,643	....	....	168,339
1899	161,783	....	215,406	....	....	377,189
1900	154,871	....	292,001	....	....	446,872
1901	199,764	....	*c* 334,833	17,651	....	552,248
1902	221,039	....	455,105	23,590	....	699,734
1903	155,828	....	467,723	....	....	623,621
1904	31,162	....	356,111	....	....	387,273
1905	139,828	....	421,331	....	....	561,159
1906	133,379	....	507,195	....	....	640,574
1907	181,063	....	500,330	....	....	681,393
1908	366,580	....	452,854	....	....	819,434
1909	356,659	....	514,066	....	59,721	930,446
1910	318,814	....	934,092	....	165,008	1,417,914

a Of this quantity, 5,932 tons were sent to Pictou, Nova Scotia.
b Of this quantity, 51,537 tons were sent to foreign ports.
c Of this quantity, 12,691 tons were sent to foreign ports.

HAYTI AND PORTO RICO

The iron-ore resources of Cuba having been discussed, those of the remaining islands of the West Indies can be dismissed quite

briefly. Jamaica and most of the smaller islands give no geologic hope for important ore deposits. Hayti and Porto Rico, on the other hand, are known to contain workable ores, and will ultimately in all probability be found to carry considerable reserves.

Iron-ore deposits, of substantially the same type as those which have for many years furnished high-grade hematites on the south shore of Cuba, are known to occur at a number of points in Porto Rico. The lack of good landings and harbors has retarded the development of these deposits, and little is known as to the reserve tonnages which they may ultimately prove to contain.

With regard to the island of Hayti, facts are really more numerous than concerning Porto Rico. It is known, for example, that large deposits of magnetite occur in the eastern part of the island; while heavy deposits of brown ores are reported from the west coast. These latter are, however, more likely to prove to be gossan ores than to resemble the brown ores of the north coast of Cuba. In any case mining development will have to be delayed until some approach to stable political conditions appears on the island. Divided now between two quasi-republics, which differ in the language and the exact tint of their citizens, there is substantial agreement in other respects. It is always possible to secure concessions from the current administration, and these concessions have a certain legal or illegal standing until the president is shot or moves the Treasury to Paris. Under such circumstances no foreigner is likely to attempt mining except within shell-range of the coast, and so far no important iron deposits have been found so conveniently located.

MEXICO

Mexico, like our own state of Virginia, is one of the areas which seem to be currently over valued as regards its iron-ore possibilities. This is not due to the entire absence of iron deposits, however, for many moderate sized deposits are known to exist, but to the location of such ore-bodies relative to fuel supplies and other industrial requisites. Furthermore, though it is of course very hazardous to say that no really heavy tonnages will ever be developed in Mexico, we can at least say that it is not as promising a territory for such discoveries as Brazil, Canada or Africa.

In discussing the iron resources and possibilities of the western

United States it was pointed out that the ore deposits so far discovered there were different in character and geologic associations from those found in the older portion of the country; and that these differences were not entirely due to the accidents of discovery, but in part to differences in the prevailing geologic conditions of the two sections. In discussing Mexico we can carry this idea somewhat further, and say that such iron ores as have been found, or are likely to be found in most portions of Mexico, will agree in character and associations with the ores of the western United States and British Columbia. That is to say, the prevalent types of ore deposits are likely to be those characteristic of modern igneous rocks in an arid area. Heavy deposits of residual or replacement brown ores are not likely to have originated in western Mexico during recent geologic periods; oölitic ores of the Clinton type are so far not known to exist; and the prevalent types are gossan ores and contact replacements. In each case we have to deal with bodies of irregular form, and difficult of estimation; and with sulphur and titanic oxide as the serious impurities, rather than phosphorus. In Yucatan and some other portions of the east coast, there are possibilities of other types of ore occurring, but so far no exploration has been turned in this direction.

The situation might be summarized by saying that the fuel and industrial conditions in the Mexican interior are likely to restrict the local iron industry to relatively small size, and that the ore deposits so far known do not promise any enormous total tonnage; that ore deposits on or near the west coast would be serviceable, even if relatively small, for supplying furnaces in British Columbia or our coast states; and that any deposits found in Yucatan would find market in the eastern United States. Under these conditions it is obvious that the only parts of Mexico which can possibly become of any importance in the international iron situation are the two coasts; and that at present the west coast shows some moderate sized ore-bodies, while the east coast is merely promising on geologic grounds.

CENTRAL AMERICA

What has been said above regarding the probable iron-ore resources of Mexico may be fairly held to apply to the reserves of

Central America, with the further limitation that in the latter case we are dealing with a far smaller area and therefore with far smaller probability of discovering serious reserve tonnages.

Iron ores have been reported from almost all of the republics of Central America, but in no cause has the importance of the discovery been sufficient to attract development of the deposits along modern lines.

CHAPTER XXIII

SOUTH AMERICA

From the standpoint of iron-ore production, South America may be looked upon as a continent of very slight present development, but of great future possibilities. Its present status as a producer will be noted later, in describing the various areas. As regards its future possibilities, it is here sufficient to say that a number of large iron-ore deposits are known to exist in various portions of South America; that one group of these, in Brazil, will probably compare favorably in total tonnage with any other ore fields in the world; and that in several widely scattered localities preparations are now being made to actively develop South American ore fields. On the other hand it will be well to recall that the existing industrial development of South America is slight; that her coal reserves are relatively unimportant; and that such coal fields as do exist, and such industrial development as is most promising, are in portions of the continent distant from the great ore supplies. Under these conditions we can hardly expect South America to become an active and important producer of iron and steel; and the ores must find a market at American or European furnaces. This is in fact the basis on which their development is now being planned; and its soundness under existing conditions will probably be thoroughly tested within the next few years.

Limited thus as regards the trend of development, we may fairly disregard the interior of the continent as a possible future ore producer, and concentrate attention on the three coastal areas which are of most immediate promise. These, which differ widely in type of ore and reserve tonnage, are:

1. The north coast, Colombia, Venezuela and the Guianas.
2. The east coast, Boazil.
3. The west coast, Ecuador, Peru and Chile.

1. COLOMBIA, VENEZUELA AND THE GUIANAS

In going over the available data relative to the iron ore possibilities of the countries lying on the northern coast of South

FIG. 54.—Map of South America showing known iron-ore deposits. (Birkintine.)

America, numerous records are found covering the occurrence of iron ores at various scattered points. Iron ores have been recorded, for example, as occurring at different localities in Colombia, Venezuela and the Guianas; but of all these localities only one seems to be so located as to give promise of attaining importance in international trade. This is the field, described in the next paragraphs, which occupies part of the Orinoco delta in Venezuela. As to the other areas, it need merely be said that brown ores which may be of the general type of those mined on the north coast of Cuba have been reported from the Guianas; and that in Colombia a small furnace has been operated quite steadily on local ores and coal for many decades. This Colombian locality is, however, in the highlands near Bogota, and the ores are therefore of no possible use to foreign furnaces.

The Venezuelan district has attracted attention at intervals during the past twenty years, but owing to political conditions and, in part, to difficult navigation, development has never been taken up very seriously. During the past year or two, however, Canadian interests have explored these deposits and are preparing to open them on a large scale. The principal known deposits are located in the delta region of the Orinoco River, and are from 50 to 85 miles from the coast. To judge from available reports, a considerable area must be assumed to be iron bearing, for definite records come from quite widely separated localities in this general region. From the data at hand now, it might be said that some 300 square miles would cover all the known deposits; but there is absolutely no certainty as to how richly this general area is mineralized. As in all thoroughly weathered tropical regions, there is evidently a vast amount of float ore covering the surface at various points, and this has led to assumptions of extraordinary thickness of ore deposits of the part of some investigators. The ore itself is mainly hematite, and reports indicate that the actual ore-bodies are lenticular deposits, of considerable length as compared to their average thickness. Some ten or twenty years ago some of this ore reached furnaces in the eastern United States; but shipments were never large and for many years past have ceased altogether.

Analyses of these Venezuelan ores most of which are quoted from a recent paper in the Iron Trade Review, are as follows;

ANALYSES OF IRON ORES, VENEZUELA

Metallic iron	68.2	65.30	66.10	66.77
Manganese	n.d.	n.d.	n.d.	0.069
Titanic acid	0.231	n.d.	n.d.	n.d.
Phosphorus	0.016	0.037	0.04	0.033
Sulphur	0.042	0.049	n.d.	0.011
Silica	0.140	3.20	2.09	0.70
Lime	n.d.	n.d.	n.d.	3.29
Moisture	n.d.	0.77	0.45	n.d.

From private reports it is known that two general types of ore deposits exist in this Venezuelan region—contact deposits and magnetite lenses. The work recently taken up appears to have been done on contact deposits, and the latest reports indicate that these have shown the usual disappointing features of that type of deposit.

2. BRAZIL

Of the countries on the eastern and southeastern coasts of South America, Brazil seems to be the only one with serious prospects of becoming an important producer of iron ore. In Brazil, however, iron ores are widely distributed, and one particular group of deposits appears to afford one of the greatest known ore reserves in the world.

The group of deposits referred to here occurs in the state of Minaes Geraes, some 300 to 400 miles north of Rio Janeiro and about an equal distance from the coast. The area in which the ores occur, as described from present knowledge, is several hundred miles square.

The ore district, according to Derby, contains two main series of rocks, both of which are probably of pre-Cambrian age. The basal series consists of crystalline schists, with many granitic intrusions. This series is overlain by a sedimentary series, consisting chiefly of quartzites and slates, with subordinate beds of limestone. The rock here spoken of as quartzite is more specifically termed *itabirite,* and is notable as varying in composition from essentially pure quartz, through a mixture of quartz and hematite grains, to pure hematite. The varieties high in iron form the bedded ores which give such importance to the district. Weathering has in places broken down the outcrops of the original beds,

so that heavy deposits of float ore occur on the slopes, while iron sands are found in the stream valleys.

The principal ore of the region is that which occurs as beds associated with the sedimentary series above noted. Leith and Harder, in describing the ores, consider that the deposits are of purely sedimentary origin, and that unlike the ores of the Lake Superior district there has been essentially no enrichment sub-

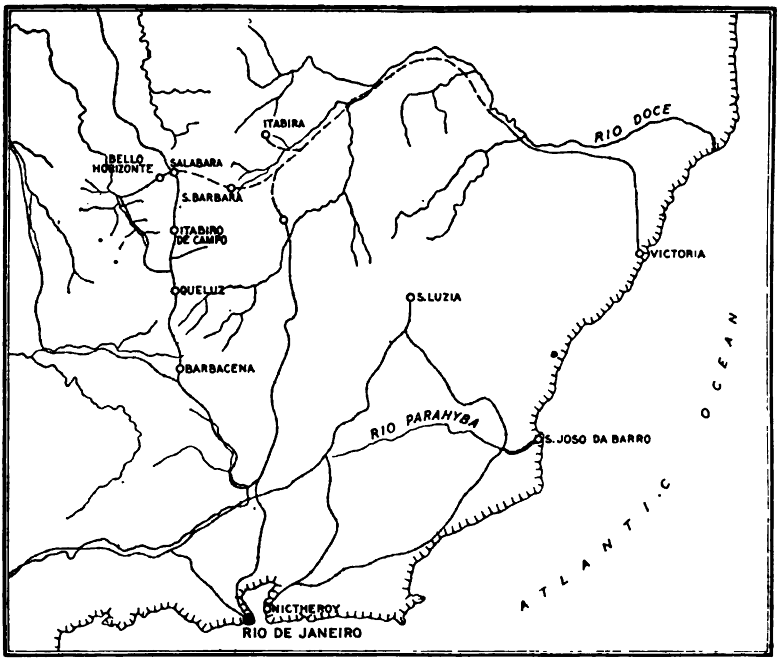

FIG. 55.—Sketch map of chief Brazilian ore region. (After Leith.)

sequent to their original deposition. These "massive ore beds vary in thickness from less than a foot to more than 300 feet, and in length to more than a mile."

The ores are chiefly hard dense hematites, though in places more or less magnetite also occurs. They vary in grade, but the average is very high in iron, and well below the Bessemer limit in phosphorus. Analyses quoted from the paper by Leith and Harder, cited in the reference list on page 304, are as follows:

ANALYSIS OF IRON ORES, BRAZIL

Metallic iron	68.22	63.99	64.29	68.82	68.67	69.35	68.79	63.01	68.77
Manganese	0.44	0.23	0.29	0.32	0.40	0.15	0.25	0.16	0.09
Phosphorus	0.049	0.033	0.087	0.044	0.013	0.010	0.017	0.184	0.015
Sulphur	0.01	0.02	0.03	0.01	0.02	0.01	0.02	0.03	0.09
Silica	0.36	0.49	0.42	0.32	0.20	0.13	0.27	1.79	0.95
Alumina	0.73	4.48	4.04	0.40	0.57	0.33	0.56	0.53	1.47
Lime	0.10	tr.	tr.	tr.	0.02	tr.	tr.	0.08	0.04
Magnesia	0.05	tr.	tr.	tr.	0.01	0.03	tr.	0.01	tr.
Moisture	0.65	3.35	3.10	0.45	0.58	0.31	0.43	6.00	0.20

As to reserve tonnages, a further quotation from Leith will serve best to explain the present status of knowledge; "Estimates of tonnage for the region as a whole would be premature with the present state of knowledge, but it is certain that the estimate of Dr. Derby for the International Congress, of two billion tons for the district, is conservative. Of the high-grade massive hematite and jacutinga ranging from 62 percent to 69 percent in iron, the tonnage is probably not far short of the total reserve of available ores in the Lake Superior region to-day. Individual deposits contain several hundreds of millions of tons." Later estimates by Merriam and Leith place the total probable tonnage for the whole region at seven thousand millions or thereabout.

3. ECUADOR, PERU AND CHILE

The occurrence of rich iron ores has been noted at various points in the Cordilleran regions of Peru and Chile, but it is obvious that transportation difficulties will suffice to rule these ores out of the world's markets for many years to come. Another series of deposits, however, are better located in this regard, and have attracted attention recently owing to the expressed intention of the Bethlehem Steel Corporation to enter upon their development. The deposits in question are located in the Coast Ranges of Chile, and the particular deposits now under consideration are in the northern part of that republic.

So far as an understanding of the geology of Chile is necessary to the present discussion, it may be summarized by saying that throughout most of its length there are three belts of rock, roughly parallel to the coast, and differing both in geologic age and character. Along the eastern boundary of the republic there are the rocks of the Cordilleras, tilted and cut by igneous intrusions, and now standing at great elevations above sea-

level. Next to the west is a zone of flatter-lying rocks, mostly sediments of Jurassic or later age. Finally, close to the coast, is a range of metamorphic schists and limestones, associated with granites and other igneous rocks. Iron ores are known to occur in all three of these series or belts of rocks; but it is only the deposits found in the coast belt that are likely to be developed commercially in the near future.

In this coastal area iron-ore deposits are found at various points, scattered almost from one end of Chile to the other, but the best prospects for development appear to be in the northern portion of the country, in the provinces of Autofagasta, Atacama and Coquimbo. The ores are chiefly hematite, with occasional magnetite, and many of the deposits are high in iron and low in phosphorus. No satisfactory data are available as to their origin or general type but such scattered notes as are on hand indicate that they are probably either replacements of some of the metamorphosed sediments, or are contact deposits of the usual western type.

The specific properties on which the Bethlehem Steel Corporation has commenced operations are known as the Tofo concessions, located about 25 miles north of the port of Coquimbo, and about 3 miles from the coast. They have been operated for some time by a French company which, a few years ago, erected two blast furnaces near the deposits. This particular group of deposits is credited with containing some 100 million tons of ore.

ANALYSIS OF IRON ORES, CHILE

	1	2	3	4	5
Metallic iron	68.20	56.64	63.29	55.56	68.81
Manganese	tr.	tr.	0.08	0.12	0.16
Phosphorus	0.011	0.039	0.210	0.029	0.036
Sulphur	0.038	0.007	0.013	0.005	0.010
Silica	1.20	9.80	3.40	12.30	1.30
Alumina	0.80	5.50	2.80	0.70	1.90
Lime	0.70	0.20	0.20	3.70	0.03
Magnesia	0.21	1.40	0.28	4.08	0.56

1. Juan Soldado mine, near Serenas.
2, 3, 4. Cerro Grande mines, near Coquimbo.
5. Pan de Azucar mines, near Guayacan.

Reference List on South American Iron Ores.—The following brief list covers a number of papers and reports dealing with

South American iron ores, sufficient to serve as a guide in further reading.

BIRKINBINE, J. Iron Ores of South America. 16th Ann. Report U. S. Geol. Survey, part 3, pp. 63–70, 1895.

DERBY, O. A. The Iron Ores of Brazil. *Iron Ore Resources of the World*, vol. 2, pp. 813–822, Stockholm, 1910.

KILBURN-SCOTT, H. Iron Ores of Brazil. *Eng., and Mining Journal*, Dec. 6, 1902.

LEITH, C. K. AND HARDER, E. C. Hematite Ores of Brazil. Economic Geology, vol. 6, pp. 670–686, 1911.

ANON. Status of Venezuelan Iron-ore Development. *Iron Trade Review*, March 20, 1913, pp. 685–687.

ANON. The Extent of the Chilian Iron-ore Deposits. *Iron Trade Review*, Feb. 20, 1913, pp. 459–462.

CHAPTER XXIV

THE IRON ORES OF EUROPE

In attempting to summarize the main facts concerning the iron ore deposits of Europe, the difficulty arises from the mass of details available, and not from their scarcity. The space available for this discussion in the present volume is necessarily limited, and in this chapter only an outline of the subject can be presented. In doing this, the ore deposits have been described by countries, except in the most important case of all—the Lorraine-Luxembourg region. The fact that this region is the most important in the world to-day might be readily overlooked if it were separated in discussion, as it is politically, among four different administrative divisions.

The order of discussion in this chapter will therefore be as follows:

1. The Lorraine-Luxembourg District.
2. Other German Ore Districts.
3. Other French Ore Districts.
4. Great Britain.
5. Norway, Sweden and Finland.
6. Spain and Portugal.
7. Russia.
8. Austria, Hungary and Bosnia.
9. Italy, Greece and the Balkan Region.
10. Belgium.

THE LORRAINE-LUXEMBOURG DISTRICT

By far the most important iron-ore district in Europe is that to be considered under the above heading. The field occupies the junction points of the French, German, Belgian and Luxembourg frontiers, and is divided, though very unequally, among the countries named. The total productive ore area amounts to almost 300,000 acres, or approximately 500 square miles and prac-

tically all of this is underlain by one or more beds of workable ore. Of the total acreage approximately 180,000 acres are in France, in the Departments of Meuse and of Meurthe-et-Moselle; 106,000 acres are in Germany, in Lothringen; a little over 9000 acres are in Luxembourg; and a few hundred acres, now practically worked out, in Belgium.

The ores occur as a group of sedimentary beds in the lower

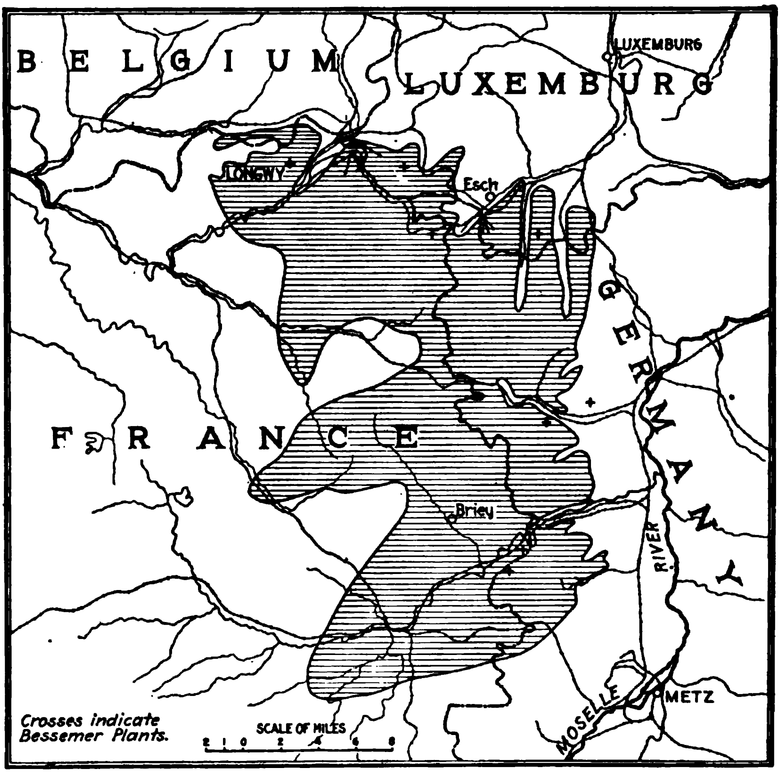

Fig. 56.—Map of Minette region of Lorraine and Luxemburg.

portion of the Jurassic series; which here outcrops in a trough dipping southwest at low angles, usually not over 2 or 3 degrees. The productive or ore-bearing portion of the series varies in thickness from 75 to 175 feet. The ore beds themselves vary greatly in number and thickness, from point to point in the area; though one of them, the so-called "gray bed," is fairly continuous and uniform. At some points eight or nine distinct ore beds

have been noted; at others there is only one bed worthy of consideration. In general, it may be said that the beds tend to decrease in number and to become individually thinner toward the southwest, while their ore also becomes more siliceous and less limey in the same direction. As the dip is also carrying them deeper below the surface as we go southwest, it is evident that the limit of workability in that direction is not definitely defined, but is a matter of economical working and of commercial grade. The limits on the other sides of the area are definitely fixed, for on the north, east and southeast the ore beds outcrop at the surface.

The ores are oölitic, like our own Birmingham red ores, and like them are of sedimentary origin. The name "minette," which is applied to them, was given as a contemptuous distinction from the "mine" ores of another horizon, which were formerly worked extensively while the minette ores were neglected. The coming of the basic Bessemer process, however, has made the formerly despised minette ores important factors in the world's industry.

Mineralogically the minette ores are composed of oölitic particles of iron oxide and iron carbonate, cemented together by a matrix which may be calcareous, siliceous, or clayey. They are often described as hydrated or brown hematites, and in fact they are chiefly so; but iron carbonate is invariably present, so that some of their iron is in the ferrous form, and some of the carbon dioxide shown on analysis is to be credited to the ore itself, and not to the limey matrix.

They are characteristically high in phosphorus, much higher than our Birmingham red ores, and are therefore well adapted for use in making pig iron to be converted by the basic Bessemer process, where high phosphorus is a necessity of the process. As has been noted, the beds vary greatly in number and thickness. Where the series is best developed, the following seven beds are found, ranged in descending order:

a. Red siliceous bed.
b. Red calcareous bed.
c. Yellow bed.
d. Gray bed.
e. Brown bed.
f. Black bed.
g. Green bed.

These vary in composition from point to point, but in general it may be said that the red, yellow and gray beds are fairly well balanced in their lime-silica ratio, while the three lowest beds are commonly both relatively and actually high in silica.

The following analyses, quoted from various sources,[1] will suffice to indicate the usual range in composition:

ANALYSES OF MINETTE ORES, LORRAINE-LUXEMBOURG DISTRICT

	Metallic iron	Lime	Magnesia	Silica	Alumina	Phosphorus	Carbon dioxide and water
Red bed; Lothringen......	40.4%	8.2%	0.5%	9.6%	5.5%	0.7%	14.0%
Yellow bed; Lothringen...	38.0	9.8	1.5	7.0	4.2	0.3	n. d.
Gray bed; Lothringen.....	31.8	19.0	0.5	7.9	2.3	0.7	22.0
Brown bed; Lothringen....	24.0	8.6	2.0	16.6	6.5	0.6	n. d.
Black bed; Lothringen....	39.7	5.9	0.5	15.1	5.2	0.7	14.0
Upper bed, Nancy........	36.0	7.0	....	11.0	....	....	....
Middle bed, Nancy.......	36.0	4.0	....	15.0	....	....	....
Lower bed, Nancy........	33.0	4.0	....	17.0	....	....	....
Lower bed, Liverdun......	32.4	14.1	....	10.32	6.02	....	....
Gray bed; Auboué........	38.64	11.20	....	6.60	5.50	0.63	....
Gray bed; Joeuf..........	37.29	14.90	....	4.50	4.98	0.62	....
Gray bed; Moutiers.......	38.24	11.30	....	6.56	....	....	....
Gray bed; Pienne.........	40.6	11.10	1.20	6.69	3.24	0.78	19.04
Gray bed; Landres........	39.20	9.05	1.05	6.20	6.10	....	18.70
Gray bed; Sancy	39.90	11.00	1.10	6.00	4.90	0.77	19.40
Gray bed; Hussigny......	35.5	7.4	....	17.2	8.3	....	15.5
Gray bed; Godbrange ..	36.3	6.8	....	15.1	9.9	....	15.5
Gray bed; Tiercelet ..	37.1	6.9	....	15.4	8.2	....	14.5

The analyses in the preceding table will serve to give some idea of the range in composition of the minette ores, in different beds and at different points. In studying them it must be borne in mind that in this case high iron content is not necessarily a test of comparative value, for the entire mining and metallurgical practice of the minette district depends upon the basic Bessemer process. In mining the aims are therefore to secure a mixture which will yield a pig iron suitably high in phosphorus for this process, and to have this mixture self-fluxing or very close to it. Reports indicate that the average furnace yield in the district is about 32 percent, which, allowing for silicon in the pig metal, means that the average ore charge must have contained about 31 percent metallic iron.

[1] Of the analyses quoted in the above table, the first five are taken from the report on the German portion of the district, by Einecke and Kohler, and the remainder from the report on the French minette ore by Nicou. Both reports are published in the volumes on Iron Ore Resources of the World, Stockholm, 1910.

Mining practice has been conditioned by the general attitude of the ores, by the presence of faults, and by advances in geologic theories. It has already been noted that the ore beds dip at 2 or 3 degrees to the southwest; and it may now be added that the field is intersected by a number of faults of considerable extent and throw. When mining first began, in the middle of the last century, the outcrop ores were of course first attacked, and for a time it was currently believed (as in our own Birmingham district) that the ores were relatively superficial replacements, and would ultimately disappear in depth. This geologic error had a curious sequel in the political history of the region. For the war of 1870–71 was in reality an exchange of blood for iron in a way that the world has not appreciated. The bulk of the fighting in the early months was in this iron region, and when the war closed France had ceded to Germany practically all of the ore outcrop, and had apparently resigned all possibility of becoming a great steel-producing nation. But the rapid spread of the basic Bessemer process gave higher value to the minette ores, and the slow spread of scientific ideas finally encouraged attempts to find them at depth. Ultimately, drilling on the French plateau showed that the ores were there in good grade, and that the reserve tonnage still retained by France is greater than that ceded to Germany in 1871.

As matters stand now part of the ore is still workable in open cuts along the outcrop, but the bulk of it is obtained by underground work. Some of the underground ore is secured by means of tunnels or slopes driven down or along the dip, either from the main outcrop or from the sides of the little ravines which cut into the plateau at various points. Another portion, becoming of increasing importance, is secured by shaft mining from points on the plateau. The working costs are low, averaging perhaps twenty-five cents per ton in the open cuts, and fifty cents per ton for shaft ore. Local furnaces can therefore get their ore charged at a total cost of not much over two cents per unit of contained iron. This is somewhat better than can be done at Sydney or Birmingham; but on the other hand the German coke cost is higher than in either Alabama or Nova Scotia, so that the total cost of making pig iron is probably higher in the minette region than in the two most closely comparable with it. When it comes to conversion into steel, how-

ever, the value of the Thomas slag probably throws the balance back again in favor of the German mills.

The district has been referred to as one of the greatest in the world, but fortunately it is possible to put the matter on a purely quantitative basis. The following figures on the ore reserves of the minette region are summarized from the International Geologic Congress report on the iron ore resources of the world:

ORE RESERVES OF THE LORRAINE-LUXEMBOURG DISTRICT

Country	Ore area, acres	Basin or field	Reserve tonnage
Germany........	106,000	a. Aumetz-Arsweiler plateau.	1,125,000,000
		b. Between Fentsch and Orne.	383,500,000
		c. South of the Orne.	321,500,000
		d. Second class limey ores.	500,000,000
France..........	180,000	a. Longwy basin.	300,000,000
		b. Briey basin.	2,000,000,000
		c. Nancy basin.	200,000,000
		d. Second class siliceous ores.	500,000,000
Luxembourg......	9,100	....	270,000,000
Belgium.........	750	Practically exhausted.	....
Total reserve tonnage, Lorraine-Luxembourg region.....			5,600,000,000

There are slight discrepancies in form between the various estimates combined in the preceding table. The French second class reserve consists of ores high in iron but also high in silica; the German second class, on the other hand, contains ores rather low in iron, but high in lime and low in silica. I have checked over some of the areas, thicknesses and tonnages, and all of the estimates seem to have been made on a very conservative basis.

In comparing this estimate of 5600 million tons of ore in the Lorraine-Luxembourg district with the figures for the Lake Superior field, the differences in average metallic content must be borne in mind. The total minette tonnage will yield perhaps 1900 million tons of metallic iron—or say two thousand million tons of pig metal. This is somewhat more than we can fairly expect from the present Lake reserves. On the other hand, it must be remembered that the minette ores are sedimentary in origin, that their total area and thickness are well known, and that therefore the present estimates of their reserve tonnage come close to giving the absolute maximum of ore workable under

present conditions. In the Lake region it is not possible to estimate so closely, and even the highest of the current Lake estimates will probably be exceeded by the facts, owing to extensions in depth and laterally on the older ranges.

In order to get an idea of the relative importance of this district as compared with other large ore producers, it is necessary to combine the statistics of production in Luxembourg, in German Lorraine, and in the French Department of Meurthe-et-Moselle. This has been done in the following table, the individual figures being taken in round numbers from a British Board of Trade report of recent date.

PRODUCTION OF IRON ORE, LUXEMBOURG-LORRAINE, 1810–1911

Years	Annual output, in metric tons			
	Luxembourg	Germany, Lothringen	France, Meurthe-et-Moselle	Total, entire district
1872–1875	1,229,000	771,000	925,000	2,925,000
1876–1880	1,507,000	785,000	1,274,000	3,566,000
1881–1885	2,423,000	1,606,000	1,906,000	5,935,000
1886–1890	2,927,000	2,675,000	2,159,000	7,761,000
1891–1895	3,482,000	3,630,000	2,876,000	9,988,000
1896–1900	5,440,000	6,075,000	3,872,000	15,387,000
1901–1905	5,616,000	9,874,000	5,039,000	20,529,000
1906–1910	6,407,000	14,245,000	9,647,000	30,299,000
1911	5,963,000	17,468,000	14,619,000	38,050,000

When summarized in this fashion, the statistics are of far more general value than when published by individual countries. The last column shows the steady increase in importance of the district as a whole, and its status relative to our own Lake region. From the other columns we get some idea of the slow growth of Luxembourg, whose production has perhaps reached nearly its maximum; of the rapid development in Lothringen for some decades; and of the recent great advance on the French side of the line, due chiefly to the deep level mines of the Briey region.

OTHER GERMAN IRON-ORE DISTRICTS

Though the Lorraine minette district just described contains the bulk of the German ore reserves, a number of other districts contain ore aggregating large tonnages. Some idea of the relative importance of the different German districts can be gained by inspection of the following table, quoted from the

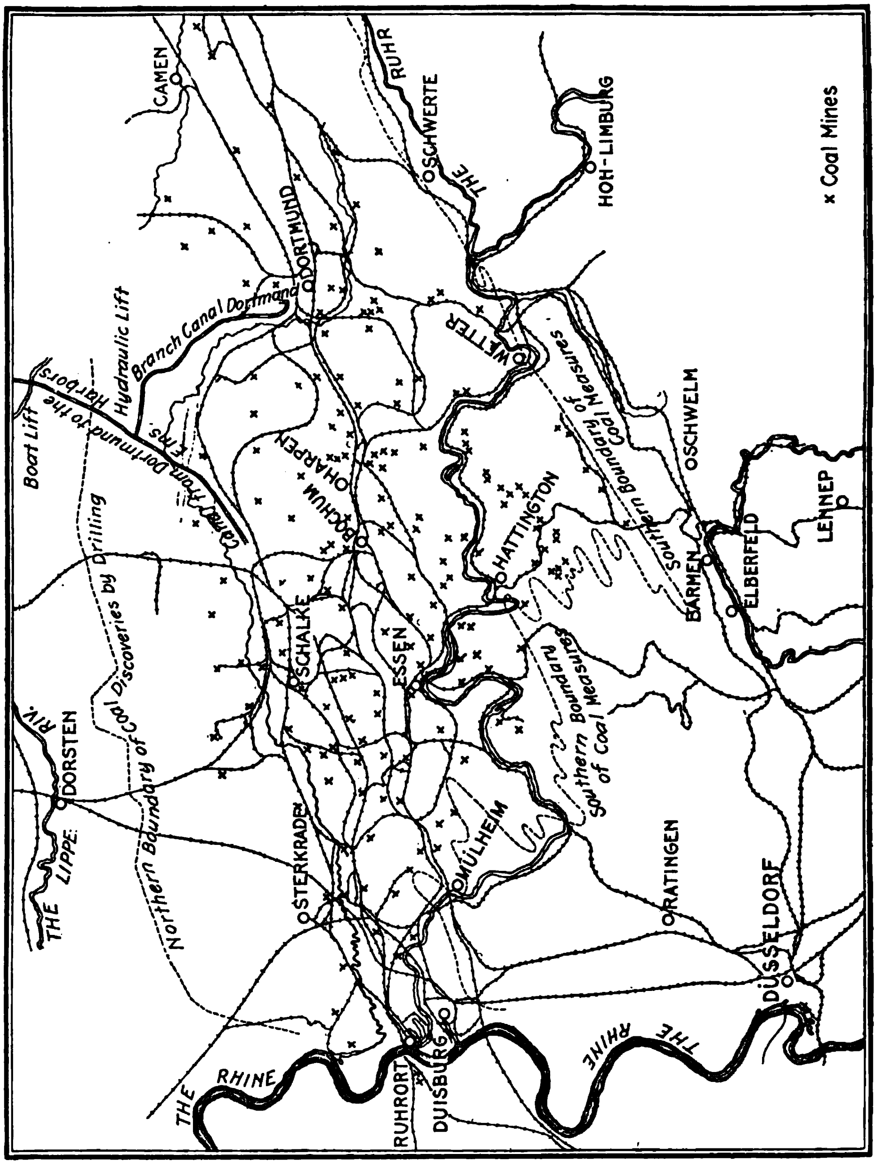

FIG. 57.—Map of Westphalian coal and iron region. (Kirchoff.)

report by Einecke and Kohler which has been previously mentioned:

IRON-ORE RESERVES OF GERMANY

	Iron-ore reserves, metric tons	Metallic iron content, metric tons
Lorraine and Luxembourg	2,630,000,000	845,000,000
Lahn and Dill districts	258,250,000	124,000,000
Ilsede and Salzgitter	278,000,000	100,000,000
Bavaria	181,000,000	62,000,000
Siegerland	115,700,000	53,000,000
Thuringia	104,200,000	46,000,000
Wurtemburg	110,000,000	42,000,000
Other smaller districts, total	230,550,000	88,000,000
Total German reserves	3,907,700,000	1,360,000,000

Of these districts, the most important from an international viewpoint is of course the Lorraine-Luxembourg region, whose output far surpasses all the others combined. Of the remainder, those which have some influence on the steel industry are the Lahn, Dill and Ilsede districts. The Ilsede ores are brown hematites of Cretaceous age, while the Lahn and Dill regions furnish sedimentary red and brown hematites from Devonian beds.

On a preceding page (p. 311) detailed statistics are given relative to the iron ore output of Luxembourg and German Lorraine. The following table, made up from a recent British Board of Trade report, will suffice to give a summary of the general iron-ore situation of the German Empire (and Luxembourg).

IRON-ORE PRODUCTION, ETC., OF GERMANY, 1872–1911

Years	Total German output	Exports	Imports	Net available for consumption
1872–1875	5,397,000	317,000	323,000	5,403,000
1876–1880	5,559,000	968,000	345,000	4,936,000
1881–1885	8,414,000	1,697,000	796,000	7,513,000
1886–1890	10,018,000	2,003,000	1,135,000	9,150,000
1891–1895	11,491,000	2,293,000	1,721,000	10,919,000
1896–1900	16,232,000	2,986,000	3.456,000	16,702,000
1901–1905	19,926,000	3,098,000	5,057,000	21.885,000
1906–1910	26,158,000	3,267,000	8,269,000	31,160,000
1911	29,399,000	2,541,000	10,647,000	37,505,000

Of the total home production, about four-fifths now comes from the Luxembourg-Lothringen minette region. The imports are

divided about equally between those from Sweden, from Spain, and from the French portion of the minette area.

OTHER FRENCH IRON-ORE DISTRICTS

Of the 3300 million tons of ore reserves credited to France, 3000 million are found in the French portion of the Lorraine region, which has been previously described. The bulk of the remaining reserve tonnage occurs in two districts, widely separated geographically, and also differing greatly in the character and association of their ores. These two districts are:

1. *Western France;* where carbonate and hematite ores are mined from beds of Ordovician age. These ores are of sedimentary origin, and occur underlying quite extensive areas. The workable portions of the beds seem to be from 5 to 7 feet thick in most of the mining districts. The following analyses of shipments from various points in Normandy and Brittany will serve to show the range in commercial ores.

	May sur Orne	Lay	Nase
Metallic iron	48.32	48.91	47.94
Manganese	0.32	0.30	0.38
Phosphorus	0.716	0.72	0.56
Sulphur	0.049	n. d.	0.01
Silica	13.80	15.79	15.71
Lime	2.54	3.01	0.08
Magnesia	1.03	1.44	n. d.
Water	4.07	4.92	2.0

2. *Southern France;* where hematite and carbonate ores are mined in the department of Pyrenees Orientales. The ores here occur as lenticular bodies, associated with metamorphosed schists of Silurian age, and probably represent replacements of limestone beds inter-stratified with the schists. The carbonates are cal-

	Port Venders
Metallic iron	57.28
Manganese	0.04
Phosphorus	0.009
Sulphur	0.33
Silica	15.8
Lime	0.08
Magnesia	0.1
Water	3.42

cined before shipment. The ores of this district are of high grade, and low enough in phosphorus for acid Bessemer and open-hearth pig. The preceding analysis gives data on this point, representing a year's shipments.

The output of the French portion of the minette region, in the Department of Meurthe-et-Moselle, has been given in a table on page 311. The following table, made up from several in a recent British Board of Trade report, gives data on the total ore production, as well as the exports and imports, of France.

IRON-ORE PRODUCTION, ETC., OF FRANCE, 1871–1911

Years	Total French output	Exports	Imports	Net available for consumption
1871–1875	2,501,000	240,000	669,000	2,930,000
1876–1880	2,447,000	88,000	958,000	3,317,000
1881–1885	2,970,000	103,000	1,406,000	4,273,000
1886–1890	2,804,000	241,000	1,314,000	3,877,000
1891–1895	3,592,000	273,000	1,582,000	4,901,000
1896–1900	4,685,000	283,000	1,988,000	6,390,000
1901–1905	5,989,000	781,000	1,761,000	6,969,000
1906–1910	10,807,000	2,970,000	1,572,000	9,409,000
1911	16,127,000	6,077,000	1,329,000	11,379,000

The minette district, it will be noted on comparing tables preceding, now furnishes about 90 percent of the total French ore output. The ore exports are mostly from this district, into Germany and Belgium. The imports are chiefly from the German portion of the Lorraine region, and from Spain.

GREAT BRITAIN

Disregarding various scattered localities and types of ore, most of which are now of merely historic interest, the iron-ore resources of the British Isles can be grouped in three classes, differing their geologic associations, their location, and their grade of ore.

These three classes are (1) the hematite ores of Cumberland and Lancashire, (2) the carbonate ores of the Mesozoic rocks, and (3) the carbonate ores of the Coal Measures. They will be described in the order named.

1. *Hematites of Cumberland and Lancashire.*—About two million tons of ore per year are mined in western England, in Cumberland and Lancashire, the bulk of the operating mines

being located near the coast, from Whitehaven southward for thirty miles or so. As later noted, this district contains most of the remaining high-grade reserves of Great Britain, and is of special interest on that account.

The ores are red hematites, and are associated chiefly with Carboniferous limestones, though some of the less important deposits occur in other rocks. The predominant type of deposit, however, is a replacement or filling in a heavy limestone bed.

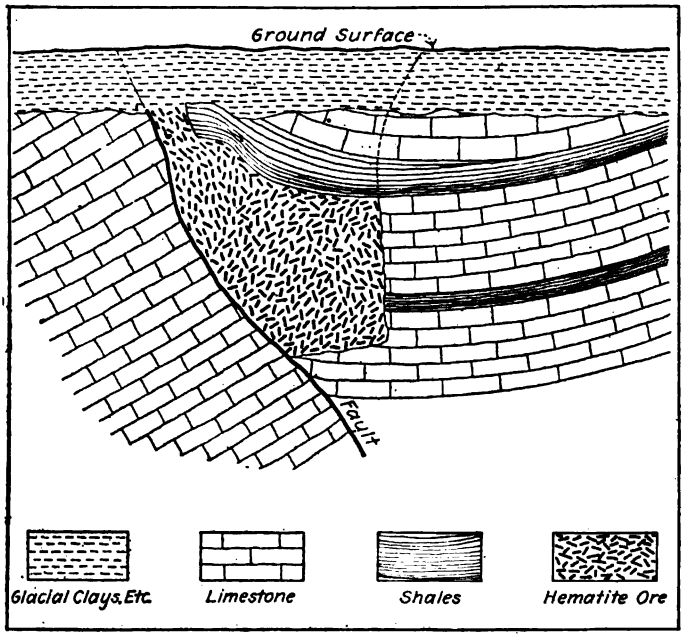

Fig. 58.—Hematite deposit, Cumberland region. (Kendall.)

The dip of the rocks varies from 5 to 25 degrees in different portions of the district, and the limestone beds differ somewhat in composition and thickness. These factors have caused differences in the size, form and general relations of the resulting ore deposits. In places the ore occurs in a tabular or bed-like form, having replaced most of a thin limestone layer; at other points the ore-body is highly irregular in form. Some of the deposits appear to owe their localization to the presence of faults in the rock-series. In addition to the replacement deposits, instances of cavity filling are known.

As to composition, the typical ores of this region are high grade so far as iron content is concerned, and low in phosphorus. The following analyses have been selected from those published by Kendall as being fairly representative of the hematite ores as usually mined and shipped.

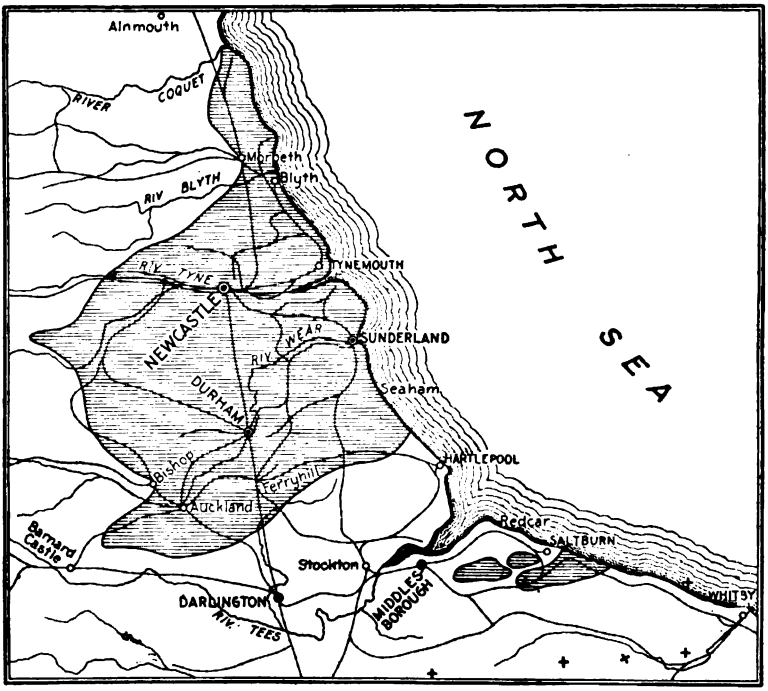

FIG. 59.—Map of Newcastle coal field and Mdidlesborough ore district. (Kirchoff.)

ANALYSES OF HEMATITE ORES, CUMBERLAND AND LANCASHIRE. (KENDALL)

Metallic iron	62.11	59.09	58.50	55.03	52.75	48.81
Manganese oxide	tr.	0.32	0.18	0.24	1.49	1.12
Silica	4.96	7.36	9.42	16.45	7.27	15.38
Alumina	1.94	0.97	1.25	1.87	2.10	n.d.
Lime	0.41	0.70	1.12	0.56	0.21	0.21
Magnesia	0.12	0.11	0.19	0.24	0.64	0.70
Sulphuric acid	0.05	0.01	0.05	0.04	n.d.	n.d.
Phosphoric acid	0.03	0.03	0.05	0.03	0.03	0.02
Water	3.10	5.00	5.55	4.34	12.54	13.54

Physically the ores range from dense massive hematite to

soft ores, high in moisture and probably in part hydrated. The last two analyses of the preceding tables are of soft ores of this type.

Some of the individual ore-bodies are of large extent, Lous for example noting one which still contains over 25 million tons of ore. The total unmined reserves of the district may easily amount to several hundred million tons. No very definite data on this subject seem to be available, however, owing probably to the great expense (per ton developed) of properly exploring deposits of this general type.

2. *Carbonates of the Mesozoic Rocks.*—These are at present by far the most important source of domestic ore supply for British furnaces, not because of their grade, but on account of their location. The principal production is in the Cleveland district of Yorkshire, where six million tons or so are annually mined; while Lincolnshire and Northamptonshire supply about half as much between them from similar beds.

The ores of this group are impure carbonates, largely altered near the outcrop to brown ore. In the Cleveland district the worked ores are found in beds interstratified with shales of Liassic age. The following general section, quoted from Kendall, will give some idea of the general relations.

		Ft.	In.
Upper Liassic shales		193	...
Middle Liassic	Iron ore-main seam	11	9
	Shale	10	9
	Iron ore	2	6
	Shale	20	0
	Iron ore	1	6
	Shale	30	0
	Sandstone	40	0
Lower Liassic shales and limestones		700	...

Of the three beds noted in the above section, only one—the topmost—is normally workable under cover. In various portions of the area where this main bed is known to occur, it ranges in thickness from 12 feet down to 4 feet or less. Louis states that in the portions of the main bed over 4 feet thick there are still some 450 million tons of workable ore.

The ore occurs in beds, and has been variously regarded as a direct original sediment, and as a replacement of limestone. The

latter conclusion is stated very definitely by some authorities, but the structural evidence offered in support of this conclusion does not seem to justify its acceptance without further investigation. On the contrary, the available records would seem to indicate that such replacement as has occurred, except locally, was probably contemporary with the original deposition of the strata involved. Pending more certain results, it appears best to consider the ores as of sedimentary origin.

As to composition, the ore mined grades from 25 to 35 percent

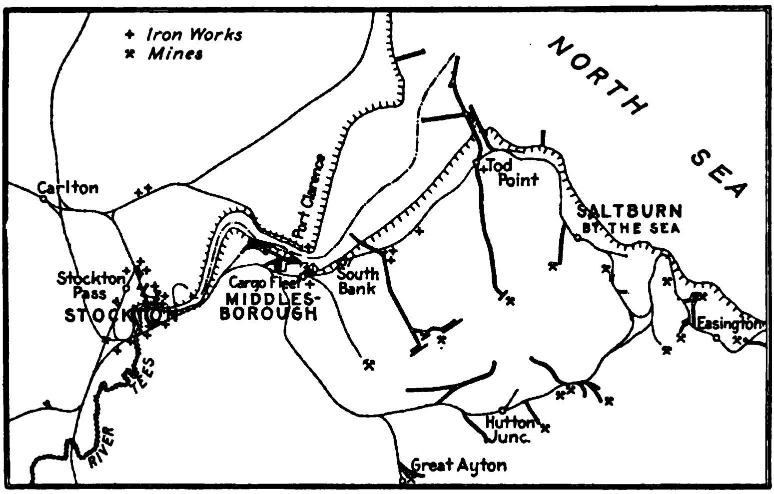

FIG. 60.—Map of Cleveland ore or Middlesboro region. (Kirchoff.)

metallic iron, and averages close to 30 percent. It ranges from 0.6 to 1.5 percent phosphorus, silica 6 to 15 percent or even more occasionally, alumina 3 to 8 percent, while lime and magnesia together average about 7 or 8 percent. The ore as mined carries 25 to 30 percent carbon dioxide and water. It is calcined before charging to the furnace, and this operation brings the iron content of the ore as used up to 40 or 42 percent.

3. *Carbonates of the Coal Measures.*—Practically all of the British coal fields contain beds of iron carbonate, varying greatly in thickness. Formerly these ores were mined to a very large extent, but now they are handled only in Scotland and in Staffordshire, which produce annually in the neighborhood of one million tons each. The tonnage remaining is enormous, but there is no

reason to consider it as an important reserve either now, or in the near future.

As can be seen from the preceding brief descriptions, the position of Great Britain as regards iron-ore resources is peculiar—perhaps more curious than satisfactory. The matter may be summarized by saying that England has still several hundred million tons of high-grade ore which would be salable anywhere; that she has in addition perhaps double that quantity of low-grade ore, workable because of its nearness to coal and markets; and that England, Scotland and Wales have thousands of millions of tons of ore now unworkable, but which may be serviceable in the future *provided* that at that future date there is still any other good reason for making steel in Great Britain. This last limitation may not be palatable, but it is really the crux of the whole question, and it seems to have been overlooked by the British geologists who have discussed the subject. People do not make iron out of low-grade ores simply to use up the ores; and with an increasing coke cost and a narrowing export market it is a very serious question whether the bulk of these British carbonates will ever be used. The duration of the British steel industry will be fixed by its coal supply, and not by its supply of local ores; for so long as coke and markets justify it, ore can be imported to good advantage. If other conditions do not justify the importation of ore, they will certainly not justify the use of these hypothetical reserve tonnages.

Statistics of Domestic Ore Production.—The following table, taken from a recent British Board of Trade report, will give the best idea of the relative productive importance of the different districts which have been described. The figures are in round numbers, and quoted in long tons.

IRON-ORE PRODUCTION OF BRITISH DISTRICTS, 1882–1911

Years	Cumberland and North Lancashire	Cleveland	East Midlands (Leicestershire, Lincoln, etc.)	Staffordshire	Wales, etc.	Scotland	Ireland	Total
1882–85	2,755,000	6,267,000	2,811,000	1,881,000	803,000	2,090,000	137,000	16,744,000
1886–90	2,569,000	5,405,000	3,005,000	1,341,000	341,000	1,226,000	138,000	14,025,000
1891–95	2,199,000	4,699,000	3,093,000	926,000	275,000	785,000	78,000	12,055,000
1896–00	1,944,000	5,639,000	4,183,000	1,025,000	252,000	887,000	101,000	14,031,000
1901–05	1,549,000	5,570,000	4,556,000	818,000	149,000	821,000	93,000	13,556,000
1906–10	1,625,000	6,158,000	5,516,000	951,000	183,000	745,000	81,000	15,259,000
1911	1,712,000	6,050,000	5,957,000	926,000	129,000	689,000	56,000	15,519,000

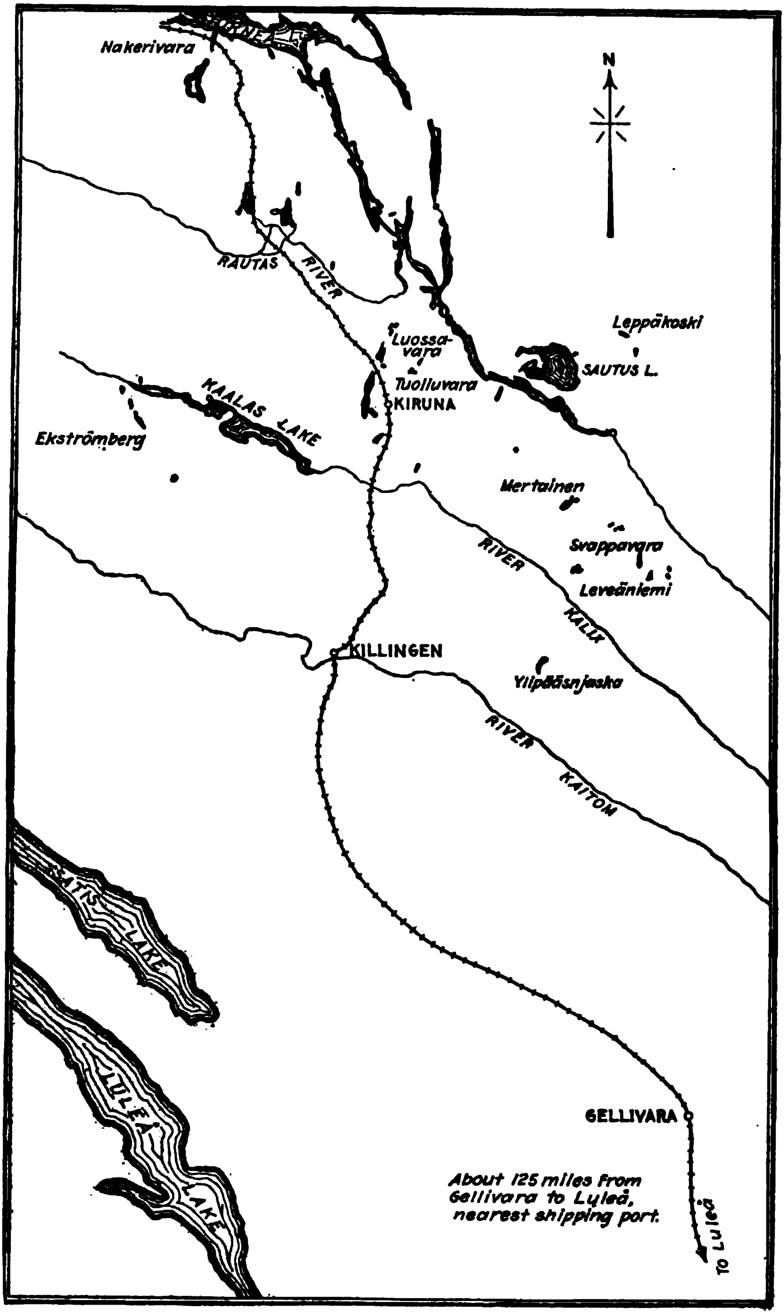

FIG. 61.—Scandinavian ore region. (Stützer.)

In addition to this domestic ore production of about 15 million tons per annum, the imports of ore have ranged from 6 to 8 million tons annually in recent years. Of these imports, about two-thirds are from Spain, the remainder being from Sweden, Norway, Algeria, Greece, Russia, etc.

NORWAY, SWEDEN AND FINLAND

Norway, Sweden and Finland possess large deposits of magnetic ore, which are at present drawn upon chiefly to supply deficiencies in the ore requirements of Great Britain, Belgium and some of the German steel-producing districts. The total tonnages available are vast, the *actual* reserves in Norway and Sweden being estimated at 1525 million tons, carrying 864 million tons of metallic iron; while the potential reserves are still larger. In some cases the ore is fairly free from gangue as mined; in others, as in the Dunderland deposits, magnetic concentration is necessary to make a merchantable product; but in all cases the grade of the final product is excellent as regards iron content.

The deposits of heaviest tonnage are found in the northern portions of Sweden and Norway, though less important deposits occur in central and southern Sweden and in northern Finland. Most of the ore deposits are associated with rocks of igneous origin, and the ore deposits have in many cases been ascribed to magmatic differentiation (see page 101). There seems to be reason to believe, however, that they are, in some regions at least, either dikes, or replacements of limestone beds along or near contact with igneous rocks.

Some idea as to actual shipping grades can be secured from the following analyses, which in most cases represent full year shipments of certain grades from given mines.

ANALYSES OF SCANDINAVIAN MAGNETIC ORES

	1	2	3	4	5	6	7	8	9	10	11
Iron	68.56	66.21	64.22	63.73	61.32	69.50	67.69	61.80	58.68	62.81	58.07
Manganese	0.14	0.12	0.13	0.13	0.187	0.46	0.12	tr	0.11	tr	0.18
Phosphorus	0.02	0.255	0.62	0.86	1.0	0.019	0.258	2.058	2.76	0.965	0.7
Sulphur	0.02	0.03	0.04	0.03	0.12	0.02	0.017	0.05	0.058	......	0.05
Silica	1.69	2.76	4.05	2.14	5.12	1.69	2.07	1.94	1.90	3.99	10.54
Alumina	0.44	1.68	1.36	0.8	1.15	0.32	0.61	0.38	0.40	0.95	0.62
Lime	0.30	1.48	2.35	3.6	3.13	0.23	0.88	6.75	8.41	3.0	1.93
Magnesia	0.48	1.07	1.01	0.9	0.73	0.45	0.46	0.15	0.24	......	1.81
Titan. oxide	0.38	0.25	.....	0.46	......	0.08	0.18	0.18	0.12	......	.....
Water	0.06	0.11	0.41	0.38	0.26	0.36	0.82	0.43	0.59	3.21	0.35

1. Gellivare, Class A, for acid Bessemer and open hearth.
2. Gellivare, Class C′, for basic open hearth.
3. Gellivare, Class C″, for basic open hearth and foundry pig.
4. Gellivare, Class D, for basic pig.
5. Grangesberg.
6. Kirunavaara, Class A, for acid Bessemer and open hearth.
7. Kirunavaara, Class C′, for basic open hearth.
8. Kirunavaara, Class D′, for basic pig.
9. Kirunavaara, Class F, for basic pig.
10. Malar, concentrates, basic and foundry pig.
11. Blotberg, basic and foundry pig. Blyth

The following table giving the iron-ore production and exports of Sweden is taken from a recent report of the British Board of Trade.

IRON ORE OUTPUT AND EXPORTS OF SWEDEN, 1891–1911

Year	Swedish ore production	Iron ore exports	Net available for home consumption
1891	971,000	171,000	800,000
1893	1,460,000	476,000	984,000
1895	1,874,000	787,000	1,087,000
1897	2,053,000	1,378,000	675,000
1899	2,396,000	1,602,000	794,000
1901	2,750,000	1,733,000	1,017,000
1903	3,619,000	2,782,000	837,000
1905	4,295,000	3,264,000	1,031,000
1907	4,408,000	3,465,000	944,000
1909	3,824,000	3,153,000	672,000
1911	6,055,000	5,005,000	1,052,000

SPAIN AND PORTUGAL

Large deposits of iron ores occur in Spain, and less well-developed and smaller deposits in Portugal. The Spanish ores are of industrial interest at present, not because they serve as the foundation of a local iron and steel industry, but because they are one of the chief sources of supply for the British Bessemer demands.

Of the Spanish ore deposits, those which were originally largest are the group located near Bilbao in the Province of Biscay (Vizcaya.) These have been drawn on heavily during the past quarter century, and of their original tonnage (estimated at some two hundred million tons) almost three-fourths have been mined. The ores consist of hematite and carbonate, are associated with

ANALYSES OF IRON ORES; SPAIN

	1	2	3	4	5	6	7	8	9	10	11	12
Iron	56.90	50.25	53.35	48.33	54.80	56.08	50.22	56.58	48.95	47.01	43.85	48.55
Manganese	0.71	1.48	0.96	0.93	1.07	0.51	0.78	1.0	3.68	2.8	2.25	0.66
Phosphorus	0.035	0.04	0.03	0.028	0.01	0.07	0.02	0.03	0.02	0.017	0.019	0.02
Sulphur	0.07	0.06	n.d.	n.d.	n.d.	n.d.	0.187	0.05	n.d.	0.048	0.15	0.34
Silica	3.79	9.51	10.03	16.33	10.56	6.78	17.83	9.0	5.72	7.03	15.35	16.15
Alumina	4.39	9.51	10.03	16.33	10.56	0.83	n.d.	n.d.	n.d.	0.14	n.d.	0.63
Lime	0.76	n.d.	0.55	n.d.	1.03	4.44	0.2	n.d.	5.29	4.88	6.0	n.d.
Magnesia	0.5	n.d.	0.5	n.d.	3.99	0.68	0.62	n.d.	1.18	1.55	n.d.	n.d.
Water	8.28	15.2	12.59	10.15	2.56	6.81	3.51	3.56	5.87	5.62	4.54	6.03

Cretaceous limestones, and probably originated by replacement of portions of these limestones.

In the Province of Lugo are a series of ore-bodies, mostly brown hematite though other ores occur, associated with schists and other metamorphosed rocks of pre-Cambrian and Cambrian age. Many of these are relatively low grade, but the total reserve amounts to a considerable tonnage.

The Provincė of Lon contains one large group of deposits, and a number less important, the whole aggregating some one hundred million tons of high-grade ore and another equal quantity of low-grade material. The high-grade ores, near Astorga, are carbonates, weathered near the surface into brown hematites; and are associated with Silurian schists in bed-like deposits.

Oviedo Province also contains a considerable reserve tonnage of bedded ores associated with Devonian rocks; and the provinces of Huelva, Sevilla, Almeria, Santander, Saragossa, Teruel and Guadalajara possess more or less important ore-bodies.

1. Santander: granular washed ore. 2. Santander: fines. 3. Bilbao: rubio. 4. Bilbao: rubio. 5. Bilbao: calcined spathic ore. 6. Malaga. 7. Sevilla. 8. Almeria; 9. Cuevas Negras. 10. Purias. 11. Aguilas. 12. Porman.

The following data on the iron-ore production and exports of

Spain are taken from a recent report of the British Board of Trade.

IRON-ORE PRODUCTION AND EXPORTS OF SPAIN, 1891–1911

Year	Spanish ore output	Iron ore exports	Net available for home consumption
1891	5,040,000	4,274,000	766,000
1893	5,362,000	4,708,000	654,000
1895	5,426,000	5,092,000	334,000
1897	7,301,000	6,774,000	527,000
1899	9,247,000	8,475,000	772,000
1901	7,779,000	6,783,000	996,000
1903	8,171,000	7,568,000	603,000
1905	8,931,000	8,452,000	479,000
1907	9,737,000	8,497,000	1,240,000
1909	8,645,000	8,048,000	597,000
1911	?	7,165,000	?

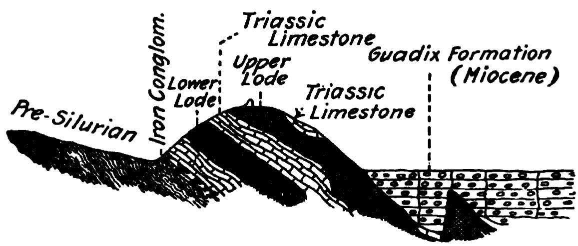

Fig. 62.—Replacement deposits, Spain. (Hobbs.)

RUSSIA

European Russia contains a large tonnage of iron ores, but the distribution of much of the total reserve is such that no immediate development can be expected commensurate with the ore available. This is brought out best, perhaps, by the following table, the data for which have been taken from the report on Russian ores by Bogdanowitsch[1] and rearranged to serve better the purposes of the present publication. The table contains data on the total ore reserves of the five principal Russian ore districts, the total metallic iron content of these reserves, and the amount of ore mined in each district during 1900 and 1906 respectively. This last item will give some idea of the present commercial development of the various districts.

[1] Bogdanowitsch, K. Iron Ores of Russia. In Iron-ore Resources of the World, Stockholm, 1910. vol. 1, pp. 363–544.

ORE RESERVES, AND PRODUCTION OF EUROPEAN RUSSIA

	Total ore reserves, metric tons		Ore mined, metric tons	
	Iron-ore tonnage	Metallic iron contained	1900	1906
Southern Russia	536,000,000	233,320,000	3,443,000	3,656,051
Ural district	281,930,345	135,355,696	1,660,632	1,242,000
Poland and northern	300,000,000	120,000,000	485,729	300,905
Central Russia	789,000,000	315,600,000	510,560	148,638
Caucasus	14,000,000	8,300,000	3,533	1,900
	1,920,930,345	812,575,696	6,103,454	5,349,494

On their face the ore reserves above noted seem satisfactory enough, and until the data are examined more critically it is difficult to explain why the relatively large finishing capacity of the Moscow and other central Russian districts is so far out of line with the comparatively small ore production of that area. As a matter of fact, however, the large total ore reserves credited to central Russia are in reality less important than they seem owing both to grade of ore and thinness of the ore-bodies. From an international viewpoint, the ore deposits of southern Russia are the ones which require most attention; for these are so located as to be of importance to foreign competitors, while the total reserve tonnage is high, and the grade of much of the ore is excellent.

The ore reserves of South Russia chiefly ores of two types, which have also a different geographic distribution. These are:

(a) Hematites occurring associated with metamorphic schists in the region of Kriwoj Rog, in the Governments of Ekaterinoslav and Cherson. These ores range from 50 to 70 percent metallic iron, though at present the lower grades are not shipped; from 0.01 to 0.06 phosphoric acid; 2 to 11 percent silica; 0.7 to 3.5 percent alumina; traces only of sulphur; ordinarily less than 1 percent of lime and magnesia together; and 0.02 to 0.08 manganese. They are now extensively worked, and it is estimated by Bogdanowitch that some 86 million tons of commercial ore still exist, of which 53 million tons will grade over 62 percent iron.

(b) In the Kertsch peninsula series of lower-grade ores occur, but their relatively low iron is made up partly by advantages of location and by the large tonnages available—estimated at some 450 million tons. The ores are brown hematites associated with Pliocene beds; and range from 34 to 42 in iron; 1

to 8 percent manganese; 1.5 to 2.7 phosphorus; and 14 to 17 silica.

The analyses below represent actual shipments from mines in the Kriwoj Rog district noted above.

ANALYSES OF IRON ORES, RUSSIA

	1	2
Iron	67.00	65.88
Manganese	n.d.	0.08
Phosphorus	0.015	0.02
Sulphur	0.018	0.026
Silica	2.88	2.96
Alumina	0.64	1.43
Lime	n.d.	1.46
Magnesia	tr.	0.39
Water	2.70	3.12

1. Kolaczewsky 2. Nicolaieff.

The following summary of the general Russian ore situation is taken directly from a recent report of the British Board of Trade.

IRON-ORE PRODUCTION, ETC., OF RUSSIA, 1891-1911

Year	Russian ore output	Exports of ore	Imports of ore
1891	1,869,000	8,000	12,000
1893	2,002,000	11,000	26,000
1895	2,704,000	17,000	22,000
1897	3,745,000	15,000	33,000
1899	5,598,000	12,000	44,000
1901	4,577,000	20,000	71,000
1903	4,071,000	305,000	81,000
1905	4,799,000	218,000	77,000
1907	5,268,000	882,000	85,000
1909	5,085,000	508,000	81,000
1911	6,832,000	869,000	106,000

AUSTRIA, HUNGARY AND BOSNIA

In taking up the Austrian Empire, we are dealing with a far less important possible source of iron ores than in the countries so far discussed. Not only is the total reserve tonnage relatively small, but other manufacturing conditions seem to indicate that Austro-Hungary has about reached its maximum importance from an international viewpoint, so far as iron and steel production are concerned. Individual plants may increase in size and output,

but hardly in the same ratio as those of France, Germany or Russia.

Of all the iron-ore deposits in Austria, Hungary and Bosnia, only two districts are of serious international importance. These are respectively Bohemia and Styria, each of which may contain several hundred million tons of workable ore. The chief Styrian ores are carbonates, occurring in large tonnages, but of course relatively low grade. The Bohemian ores include contact deposits of hematite, and also large reserves of purely sedimentary ores of lower grade. These last include both oölitic hematites and chamoisite.

As noted in an earlier chapter (p. 26) the *chamoisite* ores are hydrous iron silicates, and since ores of this type are rarely used it is of interest to quote several analyses of crude and roasted chamoisite from Uhlig's report on Austrian iron ores;

ANALYSES OF IRON SILICATE ORES, AUSTRIA

	1	1a	2	2a
Metallic iron	35.54	44.30	32.78	41.79
Manganese	0.05	0.06	0.05	0.03
Phos. pentoxide	2.05	2.55	1.52	2.13
Sulphur	0.27	.....	0.35	0.20
Silica	12.52	15.61	13.38	21.56
Alumina	7.75	9.66	13.12	13.17
Lime	3.35	4.17	3.42	1.76
Magnesia	2.28	2.84	2.08	1.28
Water, etc.	19.78	.....	18.92	0.54

1, 2. Crude Ore. 1a, 2a. Roasted Ore.

It can be seen, of course, that the two sets of analyses do not exactly correspond, but they are of value as average results nevertheless.

IRON-ORE PRODUCTION, ETC., OF AUSTRO-HUNGARY, 1891–1911

Year	Austrian ore output	Iron ore exports	Iron ore imports
1891	2,073,000	87,000	67,000
1893	2,052,000	104,000	72,000
1895	2,302,000	162,000	116,000
1897	2,986,000	244,000	133,000
1899	3,240,000	322,000	209,000
1901	3,464,000	226,000	215,000
1903	3,104,000	249,000	215,000
1905	3,518,000	318,000	224,000
1907	4,138,000	217,000	384,000
1909	4,384,000	176,000	368,000
1911	4,597,000	112,000	462,000

The preceeding data on the iron-ore production, exports and imports of the Austro-Hungarian Empire are taken from a recent British Board of Trade report.

ITALY, GREECE AND THE BALKAN REGION

The European countries which remain to be mentioned are not well supplied with iron ores, and are probably of more importance now than they are likely to be in the future. Italy has a single large mine group, on the island of Elba, which still contains a moderate reserve of high-grade ore. The Balkan countries and Turkey have not, so far as known, ore reserves of an amount which is likely to make them of international importance. Greece, however, has a series of well located deposits which are now mined on a moderate scale for export. The ores grade about 50 percent iron, but like the Cuban brown ores carry notable percentages of chromium and nickel. This gives them special value for a few purposes, but limits their general use.

ANALYSES OF IRON ORES, GREECE

	1	2	3
Iron	50.25	47.16	50.46
Manganese	2.36	0.31	0.19
Chromium	n. d.	2.31	2.27
Nickel	n. d.	n.d.	0.59
Phosphorus	0.02	0.02	0.006
Sulphur	0.015	0.04	0.029
Silica	2.29	7.18	8.37
Alumina	n. d.	9.60	7.54
Lime	7.60	2.30	0.69
Magnesia	0.50	1.49	1.91
Water	8.15	3.40	n.d.

1. Gramatico. 2. Thebes. 3. Tragana.

BELGIUM

Though a large producer of steel, Belgium is now primarily an ore-importing country, drawing its main supplies from Spain, Sweden and Germany. It still contains ore deposits of several types, but only one of these seems to give promise of being of more than temporary importance to the Belgium iron industry. This type includes sedimentary deposits of hematite, occurring as beds in Devonian rocks. The grade is relatively low, but the beds are of workable thickness over considerable areas, so that the total available tonnage is of fair amount.

CHAPTER XXV

ASIA, AFRICA AND AUSTRALIA

In taking up the three continents now to be discussed—Asia, Africa and Australia—the treatment of their iron resources can be only tentative. In the first place, there are still vast gaps in our knowledge concerning the actual occurrence of iron ores in these continents; large areas are still practically unknown, and it is not only possible but probable that some of these unknown areas may finally be found to contain very important ore deposits. But these defects in geological knowledge are unimportant compared with the uncertainty regarding the progress of general development on at least two of the continents. For, as has been suggested at various points in preceding chapters, the mere occurrence of iron ore does not of itself imply that important development is bound to occur. Before we can have any definite idea as to the international importance of a newly discovered ore-body, we must have a fair idea as to the fuel, market, labor and transportation conditions which exist now at that point, or which are likely to exist in the near future.

Under these circumstances, it is obvious that a discussion of the iron-ore resources and possibilities of Asia, Africa and Australia must of necessity be colored largely by the writer's ideas concerning the possibilities of general development in those regions. It would of course be possible to simply present a catalogue of known iron-ore localities; and perhaps this easy way out of the difficulty might be justified. In the present chapter, however, I have attempted to do something more than this, since the possible gain to the reader seems to more than balance the risk of failure. In place of presenting all available facts without comment, only such facts have been presented as seem to be of wide importance; and these facts are grouped in such a way as to suggest their probable relative effect upon the future course of the world's iron industry. The statements made are based upon good authorities; my interpretation of their relative

importance and international bearings may be faulty; the resulting discussion, at any rate, is presented as the first attempt to reach general conclusions on these important points.

ASIA

1. *China, Corea and Japan.*—These three politically distinct areas are here grouped together since their development seems likely to take the same course, and to be open to influence by the same possible changes in political and economic conditions.

In attempting to discuss the iron-ore resources or the iron-making possibilities of China, a lack of definite information regarding many important points must be taken for granted. As regards either iron or coal supplies we have to deal with numerous detached statements in the records of many travelers, with a few more definite and specific accounts of certain districts by engineers or geologists, and with fairly definite data concerning the only modern steel plant in China. The latter, operated by Japanese capital, has of course attracted the attention of political and commercial competitors; and a fairly close estimate of its manufacturing possibilities can be arrived at. But with regard to the possibilities of coal and iron development in other areas, there is ample room for serious errors in any attempt to summarize the situation and its probable line of progress.

Native iron manufacture has of course gone on in a small way for many tens of centuries; but this does not help much in attempting to locate the possibilities for modern large-scale production. Read notes many localities which seem to give promise of future importance, ranging from near Mukden in the north to Canton in the south; and some of the other papers available give details regarding specific districts. His final conclusion is that the chief iron development is likely to take place in the Yang-Tze valley, where good ore supplies and adequate water transportation to markets are available. The one modern plant of China is already located in this area, at Hanyang opposite Hankow in Hu-Pei province.

The ore used at the Hanyang furnaces is mined at Ta-Yeh, 50 miles southeast of the plant. Read states that this ore is a hematite, occurring in large bodies along the contact between syenite and a Devonian or Carboniferous limestone. The ores grade between the following limits: 60 to 62 percent iron; 0.05

to 0.25 percent phosphorus; 0.05 to 0.12 sulphur; 3 to 5 percent silica; 1 to 2 percent alumina; 0.2 to 0.4 percent magnanese; and 0.05 to 0.25 percent copper. The ore-bodies now worked are credited with containing about 100 million tons of commercial ore. The coke used is from Ping Hsiang, 300 miles south of the furnaces; and manganese ore is obtained in the same locality as the coal.

Read's figures on costs at Hanyang are illuminating, and will justify quotation.

"The cost of production of iron ore in the open-cut workings at Ta-Yeh is approximately as follows:

	Mexican per ton.
Stripping	$0.08
Mining	0.18
Tramming	0.03
Powder, steel, etc.	0.015
Superintendence	0.06
Loading, freight to Hanyang, etc.	0.30

This would make the probable cost of the ore delivered at the blast furnace a little under $1.00 Mexican per ton. Ordinary unskilled laborers receive $0.08 to $0.12 gold per day. Skilled labor receives $10 to $50 Mexican per month; and the efficiency of this labor is remarkably high."

As to the iron ores of Japan, they are widely distributed, and the total available tonnage is fairly large, though no single very large deposits are known to exist. Inouye states that the most important ore-bodies are contact deposits associated chiefly with Paleozoic limestones near their contact with igneous rocks. At the largest of these deposits, that of Kamaishi, the ore is a magnetite ranging from 55 to 60 percent in metallic iron, and usually low in phosphorus. In other deposits the ores are hematites of substantially similar grade. Five deposits of various types are now producers; the magnetite deposits of Kamaishi, Nakakosaka and Hitokabe, the hematite of Sennin, and the iron sands of Chugoku. Inouye estimates the reserve tonnage in the best known of these deposits at a total of about twenty million tons; but the unexplored reserves are possibly far larger.

Inouye states that the Japanese iron industry dates back to the seventh century, and that in its earliest form it was based on the

use of iron sands as ores. The Imperial Iron Works, founded in 1896 and completed in 1901, has placed the industry on a modern footing. At these works about 200,000 tons of Japanese, Corean and Chinese ores are smelted yearly, yielding about 100,000 tons of pig iron, all of which (and more) is used in the steel plant. In addition, some 40 or 50 thousand tons of pig are made at smaller furnace plants; and 60 thousand tons or more are annually imported. These figures are noted here, for in most statistical summaries the entire production of the Imperial works seems to be overlooked, so that we are in danger of crediting Japan with much less iron and steel making capacity than she actually possesses.

2. *British India.*—Three main types of iron-ore deposits seem to offer possibilities in the way of successful ore mining and iron manufacture in British India, though these three types differ greatly in their adaptability to these purposes. The types noted are respectively:

a. Hematite and magnetite deposits, associated with pre-Cambrian rocks, and occurring in Madras, Bengal and central India. These ores are in places merely disseminated through masses of igneous or metamorphic rock, and will require concentration to be serviceable. But at other points we have to deal with deposits which, because of either original greater richness or secondary concentration, show definite ore-bodies containing high-grade ore. Two of these richer fields have attracted attention recently, as being the scene of the operations of the Tata Steel Company, in which American engineers are interested. These two areas are located respectively in Orissa (Bengal) and near Raipur (Central Provinces). The former field is the one which is expected to furnish the immediate supply for the Tata plant, which is located near Kalimati, 45 miles from the ores and 150 miles from Calcutta. Both the Orissa and Raipur ores are chiefly hematite, and in each case several hundred million tons of ore are supposed to exist. The Orissa ores carry 64 to 69 percent iron, 0.048 to 0.135 phosphorus, 0.021 to 0.036 sulphur and 1.64 to 4.08 silica.

b. Carbonate ores in the Coal Measures of Bengal have been used by the natives and by the Barakar iron works for many years as a source of iron. The Barakar plant formerly obtained its entire supply from nodular carbonates occurring in shales in the Raniganj coal field; but recently magnetite and hematite ores

from near Kalimati have been used at the three Barakar furnaces. The carbonate ores analyzed 43.43 percent iron, 16.49 percent silica, 2.15 percent manganese and 0.86 percent phosphorus. Approximately 100,000 tons per year of ore are used, on the average, at this plant, its output of pig metal ranging not far from 40,000 tons per year.

c. Residual brown ores, often highly aluminous, occur in quantity in the laterite formation in the presidencies of Madras, Bengal and Bombay. Much of these ores are too low grade, or too aluminous, to be worthy of consideration either now or in the near future; but in places analyses are reported which indicate ores at least as good as those mined in Cuba from similar deposits.

From this brief outline it can be seen that the ore resources of British India are still far from being known definitely. Holland, in his summary, cautions against a too-enthusiastic view of the matter, pointing out that the number of small native bloomaries gives no indication as to the existence of really heavy reserves from a modern viewpoint. But, as against this, we must consider that within the past ten years Bose discovered and described two entirely new ore fields; and that when the engineers for the Tata plant tested these fields, they reported an aggregate reserve of some 400 million tons of ore, grading over 60 percent iron. Unless we are willing to assume that, by sheer good fortune, the only good ores in India were thus placed in the hands of the Tata company, we must be prepared to expect heavy tonnages to be turned up in other parts of a country which can produce two such excellent ore fields. On this account I am inclined to credit India with far heavier possible reserves than are considered probable by the Estimates of the Indian Geological Survey.

As to the extent to which these resources are likely to be developed, that is another question. There are no foreign furnaces so located that they can draw upon India for a portion of their ore supply, so it may be taken for granted that all of the mining development will be with the idea of using the ore in Indian iron works. The coal and labor supplies seem to be ample to permit such local development; and the markets reachable should be sufficient to take a far heavier tonnage of iron and steel than are now produced in India. The matter seems to rest indeed largely in the hands of the Government; and the manufacturing

development of India may depend almost entirely upon larger questions of political and economic policy.

AFRICA

Our knowledge of the iron-ore resources of the African continent is necessarily still very indefinite, and a mere summary of the scattered data would be of little real service to our present work, for it would be difficult to put a catalogue list of African ore deposits into such form that any valuable conclusions could be drawn from it. On the other hand, certain general conclusions seem to be justified, in the light of our present knowledge. These conclusions are of course matters of purely personal judgment, and it may turn out that they are erroneous; but they are offered now as representing, in the opinion of the writer, the really important facts that seem to underlie the mass of scattered details which are now available. They may be summarized as follows:

a. Large areas of the African continent, including much of the west coast, have so far either failed to show iron deposits, or are so handicapped by climatic conditions that serious development would be doubtful, even if iron ores are found.

b. The north coast region, from Morocco to Tripoli, contains a series of more or less important iron-ore deposits. These are now partly developed, and the undeveloped areas will undoubtedly soon be opened up. But the deposits of this region will serve as a source of supply for European furnaces, rather than as a basis for the growth of a local iron industry.

c. In eastern and southeastern Africa an entirely different state of things exists. Here we have no deposits now developed, and we have no really definite data respecting the undeveloped deposits. But throughout a large area we do have notes on the occurrence of iron ores of a type which may readily become important, and so far as can be judged now, may perhaps become more important than any of the other African fields. This region is suitable for white habitation and labor in most parts, and coal fields occur at various points in it. The data are plainly insufficient for final conclusions; but they obviously point toward the possibility that we are dealing here with a region which may become the location of an important iron production.

For our present purposes we may entirely disregard the areas

which seem unlikely, for any reason, to become of serious international importance, and concentrate attention upon the two regions which do give promise.

1. *The North African Coast Region.*—For the four divisions making up this region, there are available very complete data on the iron ores of Algeria, fairly full data on Tunis, and practically nothing on Morocco and Tripoli. It is known that the iron-ore deposits of Morocco have been examined by German and French engineers, but nothing definite on the result of these explorations has been published. The following summary must of necessity, therefore, relate almost entirely to conditions in Algeria, but the practical certainty that heavy tonnages exist in the other states must not be overlooked.

For a number of years past heavy tonnages have been shipped from Algerian mines to European furnaces, and in later years Tunis has added to these shipments, which now average close to one million tons a year. All of this ore is a rather high-grade hematite, ranging from 50 to 60 percent iron, and low in phosphorus. The ore-bodies are lenticular in shape, associated with schists and limestones, and probably represent replacements of the latter. Similar deposits occur in Tunis, and Nicou estimates the total reserve tonnage of these two French colonies at from 100 to 150 million tons of commercial ore.

ANALYSES OF IRON ORES, ALGIERS

	1	2	3	4	5
Iron	57.10	43.65	52.62	49.70	50.42
Manganese	1.2	1.1	4.88	1.30	1.39
Phosphorus	0.009	0.02	0.01	0.035	0.019
Sulphur	0.017	0.04	0.045	0.08	0.028
Silica	3.64	12.77	4.64	5.45	4.74
Alumina	0.49	n.d.	0.74	n.d.	n.d.
Lime	1.22	2.91	0.12	9.9	7.49
Magnesia	0.24	0.54	1.14	0.43	0.42
Water	8.65	6.18	7.04	9.75	9.08

1. Timezrit. 2. Oued-Djer. 3. Bar-el-Maden. 4. Temoulga. 5. Zaccar.

2. *Eastern and southeastern Africa* seems to contain, in most of the provinces and colonies, iron deposits of more or less importance; and in some of the areas these appear to be of great promise. For convenience the region will be taken up by administrative divisions, from north to south.

In Egypt and the Soudan only scattered records as to iron de-

posits are available. These appear to indicate the presence of workable brown hematites in Darfur and Kordofan; and of widely distributed deposits of oölitic ores associated with a series of sandstones. No really definite data as to possible tonnages or working conditions seem to be available, but analyses of various samples are fair.

Magnetites and other ores are reported from Uganda, British Somaliland, and the East Africa Protectorate, the latter province being apparently of most promise in this regard. Magnetite and hematite ore-bodies are also known to occur in German East Africa, and in Nyasaland. The Congo also reports considerable ore tonnages.

In the three divisions still to be mentioned—Rhodesia, the Transvaal and Cape Colony—the matter assumes a more definite and important aspect. Many types of ore exist here, and some of these may attain commercial importance. Mennell estimates for example, that there are several thousand million tons of lateritic ores in Rhodesia alone—brown ores much like those of Cuba, frequently high in alumina and always high in silica—but the most promising type is a hematite associated with pre-Cambrian rocks, like the Lake Superior and Brazilian deposits. Mennell considers this last type of deposit to be, in Rhodesia, of high possible economic importance. Similar deposits occur in corresponding rocks in the Transvaal, but are not supposed there to be workable. Contact deposits of later age are, however, promising at various localities in the Transvaal.

The entire matter as to the possible economic importance of these east African deposits must be left unsettled until they are examined by some one acquainted with iron mining elsewhere. As it stands now the data are only sufficient to justify the suggestion that here is very possibly one of the large ore fields of the world. But careful examination may show that this is an error.

AUSTRALIA

Though considerable information is available concerning the iron-ore deposits of Australia and New Zealand, much of it is curiously indefinite and amateurish in its form of statement, and apparently prepared by geologists who have had little or no acquaintance with iron-ore mining in developed districts. There is, therefore, a distinct lack of comparative value in most of the

data obtainable. The brief summary which follows must be read with this fact in mind.

New Zealand contains the largest deposits at present known, those of Parapara, which are brown ores associated with and probably replacing, crystalline limestones of Ordovician age. Magnetite beach sands also occur, but with high titanium content.

New South Wales ranks next in developed iron-ore tonnage, and because of its coal resources, these ores attain considerable industrial importance. Those of the Cadia field are in largest quantity.

Tasmania contains one promising ore field, that of the Blythe River district, where hematites are associated with Ordovician rocks.

Victoria, Queensland, West Australia and South Australia contain scattered deposits, some of fairly large size, but few so located as to give much promise of attaining industrial importance in the near future. Some of the largest, moreover, seem from the data available to be deposits of contact origin, and therefore open to suspicion as to their composition in depth.

ANALYSES OF IRON ORES, AUSTRALIA AND NEW ZEALAND

State	Locality	Metalic iron	Silica	Phosphorus	Sulphur	Water
West Australia.	Wilgi Mia	63.87	2.48	0.090	0.033	2.41
West Australia.	Wilgi Mia	64.36	1.38	0.052	0.023	1.17
South Australia.	Cutana	62.49	6.26	0.05	....	1.16
South Australia.	Cutana	49.73	18.47	0.03	0.15	5.08
South Australia.	Iron Monarch	66.08	1.19	0.02	....	1.23
South Australia.	Donnellys	58.68	0.67	1.03	0.05	11.22
Queensland.	Mt. Leviathan	64.72	2.51	0.065	.....	0.13
New South Wales.	Carcoar	58.03	4.93	0.154	0.015	5.78
New South Wales.	Carcoar	56.49	7.88	0.064	0.04	7.35
New South Wales.	Cadia	61.38	9.22	0.051	0.099	1.53
New South Wales.	Cadia	59.65	11.28	0.17	0.028	n.d.
New South Wales.	Cadia	57.96	12.04	0.023	0.05	3.20
New South Wales.	Queahbeyan	64.88	6.04	0.011	0.008	0.69
Tasmania.	Blythe River	68.7	1.6	0.04	tr.	n.d.
Tasmania.	Blythe River	68.6	1.8	0.09	tr.	n.d.
New Zealand.	Parapara	58.19	3.09	0.16	0.13	9.64
New Zealand.	Parapara	51.39	9.56	0.17	0.11	11.84
New Zealand.	Parapara	56.75	4.90	0.18	0.40	9.65

PART IV.—EXTENT AND CONTROL OF IRON-ORE RESERVES.

CHAPTER XXVI

THE EXTENT OF AMERICAN IRON-ORE RESERVES

The Credibility of Reserve Estimates.—Before going on to a statement of the various estimates which have been made as to American and tributary iron-ore reserve tonnages, it may not be amiss to consider briefly the manner in which such estimates are made, and the extent to which they can be relied on. Though the matter is purely technical in its nature, it should be possible to explain its principles and results in non-technical language.

There are three different sets of factors involved in making an estimate of the tonnage of ore contained in any given property or region. In each case, whether the area and tonnage considered be large or small, we start from a basis of engineering facts, interpret and utilize these facts by means of geologic deductions, and finally correct our tonnage estimates in the light of industrial conditions. An example may make this clearer, and since the principles involved do not vary with the size of the area, we may assume that a single small property is under consideration. In attempting to determine its ore tonnage, there are to be considered first of all the facts that workable ore is shown in some or all of a number of natural exposures, artificial openings, test-pits, or drill-holes. These facts as to occurrence and thickness must be interpreted geologically, for the isolated records mean little unless some idea can be secured as to the form and geological relations of the ore-body. Finally, consideration must be given to the effects of ore grade, working conditions, transportation, etc. It will be seen that the industrial factors last mentioned are really the ones on which differences of opinion can most readily exist. Two men of approximately equal experience and training can hardly differ as to the records of the drill-holes; they may differ somewhat as to the geologic interpretation of those records;

but they may differ very widely in their ideas as to how much of the ore can be considered available under existing industrial conditions. When the problem is rendered more complicated by attempting to determine what ore will be available under *future* industrial conditions, the differences in opinion are apt to be still wider.

This is an important fact, and must be borne in mind when comparisons are made between tonnage estimates by different authorities. When these estimates differ widely, examination will usually show that there is substantial agreement as to the facts of the case, and that the differences in the final statement are due chiefly to the point at which the line between available and non-available ore has been drawn. In considering the various estimates which have been made as to the total iron-ore reserves of the United States, which will next be taken up, this phase of the matter must be kept in mind steadily.

It is difficult enough to arrive at a definite comparative valuation for two different ores, to be used in the same region and in a given year when all trade conditions are known. But the problem becomes immensely more difficult when the comparison is extended to cover a large number of ores, to be used at many different points and during a long series of years under unknown and variable trade conditions.

If an investigator of this problem wished to give an air of mathematical precision to his results, he would have to take into consideration differences in grade, character and amount of impurities, mining costs and conditions, concentration results, nearness to furnaces and to coke, labor costs and pig-iron prices. These factors would be complicated by variations in general business conditions, by the competition of new ore supplies, and perhaps by changes in tariffs.

It will be seen that to attempt a rigidly mathematical treatment of the problem would be ridiculous, for the unknown variables would make the apparently precise results merely fallacious. In this, as in other problems involving future conditions, it will be best to put aside all attempt to secure misleading precision, and to be content with working out the problem in a manner which will yield serviceable and reasonably accurate results. For most of the purposes of life it is better to be approximately right than precisely wrong.

At the outset the reader will do well to understand that estimates of our total iron-ore reserves, and anxiety over their probable duration, are matters of very recent date. England has suffered periodically, for almost a century, from attacks of panic over the impending exhaustion of her coal supply; and the duration of our own supply of Pennsylvania anthracite has been a subject of serious discussion for some time. But the fear of exhausted iron ores does not date back as much as ten years, and its commencement in this country was due to the publication of a foreign report whose absurdity should have been enough of itself to render it harmless.

The Törnebohm Estimate of 1905.—In 1905, in response to a request from the Swedish Parliament, an eminent Swedish geologist, Professor A. E. Törnebohm, prepared a report on the iron-ore resources of the world. In its original form, the report attracted little notice in the United States, even among those directly interested in the iron industry. Early in 1906, however, a summarized translation of the report was forwarded home by the American consul at Paris, and the wide circulation which is given to consular reports in the United States resulted in drawing considerable attention to the matter in both the daily and the technical press.

The character of the Törnebohm report, in the form in which it reached the American public, is fairly indicated by the following extracts:

"It will surprise a great many to learn that we are likely to run short in iron inside of a single century, if we keep up the present rate of consumption. As a matter of fact we are more likely to increase the consumption than we are to reduce it. The world has only 10,000,000,000 tons of iron ore available. Of these Germany has twice as many tons as the United States. Russia and France each have 400,000,000 tons more than this country. * * * Assuming therefore as true the claim of geological science that the extent of workable iron-ore beds is known to within a margin of possible error not exceeding 5 percent, the Swedish report, which is based upon the most authoritative information, has naturally attracted world-wide attention. * * * The present output of ore and the amount of ore actually consumed by each is as follows, in tons:

Country	Workable deposits	Annual output	Annual consumption
United States	1,100,000,000	35,000,000	35,000,000
Great Britain	1,000,000,000	14,000,000	20,000,000
Germany	2,200,000,000	21,000,000	24,000,000
Spain	500,000,000	8,000,000	1,000,000
Russia and Finland	1,500,000,000	4,000,000	6,00,0000
France	1,500,000,000	6.000,000	8,000,000
Sweden	1,000,000,000	4,000,000	1,000,000
Austria-Hungary	1,200,000,000	3,000,000	4,000,000
Other countries	1,200,000,000	5,000,000	1,000,000
Total	10,000,000,000	100,000,000	100,000,000

"While it is probable that the foregoing statement does not take into adequate account the undeveloped ore deposits of Utah and Alabama, its teachings are nevertheless obvious and impressive. Of the world's workable iron-ore deposits, as at present known, the United States possesses only about one-ninth, and at the present rate of consumption the entire supply will be exhausted within the present century."

Of the eleven hundred million tons credited by Törnebohm to the United States, an even ten hundred million were to come from the Lake regions; sixty million from Alabama, with some evident doubt by the Swedish geologist as to what these Alabama ores really were; and the remaining forty million were widely distributed.

If properly understood, as a report intended to assure the Swedish people that they controlled a very respectable percentage of the world's supply of high-grade ores, the Törnebohm report was really effective. From any other point of view it should not have been taken seriously. Its publication by our Consular Bureau, however, gave it a semi-official aspect; and in its summarized and annotated form its newspaper career was amazing.

At different times in 1905 and 1906, the Törnebohm report was discussed in print by various authorities. Among others, Hadfield, Shaler, Birkinbine and Leith mentioned it or treated phases of the same subject, while most of the technical journals commented on it editorially. Practically all these commentators deprecated the low estimates of the Swedish geologist, but no new data for revised estimates were offered as substitutes.

The Eckel Estimate of 1907.—The following extracts will serve to fix a stage in the development of ideas regarding the iron-ore reserves of the United States:

"The Lake Superior district, at present the leading American producer, has been explored more thoroughly than any other ore field in the United States, but estimates as to total tonnage range within rather wide limits. At present the totals commonly quoted vary from 1,500,000,000 to 2,000,000,000 tons.

"In the Rocky Mountain and Pacific States a few large iron-ore deposits are known to exist, and many others are reported, but any attempt at an estimate of total tonnage would be, with only our present knowledge of the subject, merely the wildest sort of guessing.

"A more promising field lies in the older eastern States. It is probable that careful exploratory work will develop magnetic iron ores in New York, New Jersey and Pennsylvania in quantities far in excess of anything usually considered possible in those states. Here also close estimates are impossible.

"With regard to the southern iron ores the case is very different. Here the work which the Geological Survey has carried on during the last three years, which was planned so as to obtain data on the quantity of ore available, gives a fairly secure basis for tonnage estimates. It is safe, therefore, to submit the following figures as representing minimum values for the workable iron-ore reserves above the 1000-foot level in certain southern States, with the caution that further exploratory work in the South will probably greatly increase rather than decrease these estimates:

	Red ore, tons	Brown ore, tons
Alabama	1,000,000,000	75,000,000
Georgia	200,000,000	125,000,000
Tennessee	600,000,000	225,000,000
Virginia	50,000,000	300,000,000
Total	1,850,000,000	725,000,000

This gives a total estimated reserve, for the red and brown ores of the four states noted, of over 2,500,000,000 tons. If to this we add the ores occurring at deeper levels in the states named, and also the red and brown ores of Maryland, West Virginia and Kentucky, and the magnetic ores of the other southern States, it is probably fair to assume that the total southern ore reserves will amount to very nearly 10,000,000,000 tons. * * * Much of this ore is, of course, unworkable at the present day, but all of it should be counted on in any estimate of total ore reserves. * * * It may be further added that the estimates as to red-ore tonnage are probably much more accurate than those relative to brown ores.

"To sum up the matter, in place of the 1,100,000,000 tons credited by the Swedish geologist, it is probably safe to say that the United States has from ten to twenty times that reserve of iron ore."

These large totals were intended to include not only the ore of strictly available present-day grade, but the ores which could be reasonably expected to come into use within the next thirty or forty years, for the question under consideration at the moment was the possible ultimate exhaustion of the American iron supply. No attempt, however, was made to include the very large low-grade reserves either in the Lake regions or in the South, for the writer felt that the use of such ores would be put off to very remote periods, owing to the increasing importations of ore. This opinion he still retains, as will be seen later.

The Hayes Estimate of 1908.—No one connected with the American iron industry was really worrying over a possible shortage in our ore supply, and the matter might perhaps have been dropped at this stage if it had not become entangled with the conservation problem which about that time was being considered by a strenuous executive, a puzzled Congress, and a series of excited organizations ranging from sewing circles to lumber dealers. Everyone who remembers that remarkable episode will recall with pained surprise the unanimity with which we all considered gloomily, in turn, the impending scarcity of the food supply and the possible utilizations of sawdust; the decreasing number of western farmers and the increase in southern boll-weevils; the substitution of steel for timber, because wood was a luxury—and then later the substitution of concrete for steel because steel would be reserved for coinage. Looking back at it, the pity of it is that all of this national worry was so futile; for how many of the good resolutions made then have been kept? We have, it is true, a more efficient forest service, and a tangible forestry plan. Also, it might be added, the pension list has been kept from decreasing, the Alaska coal is yet intact for future generations, and congressional mileage is still jealously conserved. But with these striking exceptions, the net gain has been very small in proportion to the enthusiasm developed.

One of the good features of the conservation movement was the establishment of a commission to inventory the more important raw materials of the United States. The examination of the iron-ore question was assigned to C. W. Hayes, then Chief

ESTIMATES OF IRON-ORE SUPPLIES OF THE UNITED STATES (C. W. HAYES)

Commercial districts (States)	Magnetite ores			
	Non-titaniferous		Titaniferous	
	Available	Not available	Available	Not available
	Long tons	Long tons	Long tons	Long tons
1. Northeastern......	160,000,000	111,500,000	90,000,000	100,000,000
2. Southeastern......	*a* 12,500,000	23,000,000	....	....
3. Lake Superior.....	....	4,500,000,000	....	25,000,000
4. Mississippi Valley .	....	....	....	....
5. Rocky Mountain ..	*a* 51,485,000	*a* 115,440,000	....	1,500,000
6. Pacific Slope.......	*a* 68,950,000	11,800,000	....	2,000,000
Total...........	292,935,000	4,761,740,000	90,000,000	128,500,000

a Includes some hematite.

Commercial districts (States)	Hematite ores			
	Specular and red		Clinton	
	Available	Not available	Available	Not available
	Long tons	Long tons	Long tons	Long tons
1. Northeastern...	2,000,000	2,000,000	35,000,000	620,000,000
2. Southeastern...	8,000,000	53,000,000	463,540,000	970,500,000
3. Lake Superior..	3,500,000,000	67,475,000,000	10,000,000	30,000,000
4. Mississippi Valley.	15,000,000	10,000,000	....	....
5. Rocky Mountain.	4,275,000	2,100,000	....	....
6. Pacific Slope ...	....	10,000,000	....	....
Total........	3,529,275,000	67,552,100,000	508,540,000	1,620,500,000

Commercial districts (States)	Brown ores		Carbonate ores	
	Available	Not available	Available	Not available
	Long tons	Long tons	Long tons	Long tons
1. Northeastern.......	11,000,000	13,500,000	....	248,000,000
2. Southeastern.......	54,400,000	168,000,000	....	62,000,000
3. Lake Superior......	....	....	....	....
4. Mississippi Valley ..	300,000,000	560,000,000	....	....
5. Rocky Mountain ...	2,000,000	1,625,000	....	....
6. Pacific Slope.......	....	105,000	....	....
Total............	367,400,000	743,230,000	....	310,000,000

Geologist of the United States Geological Survey; and the result was the publication of a most important and detailed estimate

of our total iron reserves. Dr. Hayes had a wide acquaintance with American iron ores; and sufficient time and money were available to do the work properly. His report must stand as the basis for all future discussions of this subject.

1. Vermont, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Maryland, Ohio.
2. Virginia, West Virginia, eastern Kentucky, North Carolina, South Carolina, Georgia, Alabama, east Tennessee.
3. Michigan, Minnesota, Wisconsin.
4. Northwest Alabama, west Tennessee, west Kentucky, Iowa, Missouri, Arkansas, east Texas.
5. Montana, Idaho, Wyoming, Colorado, Utah, Nevada, New Mexico, west Texas, Arizona.
6. Washington, Oregon, California..

Hayes' final figures, by districts, are shown by the table below.

Districts	Total reserves, in tons Available	Not available
Northeastern	298,000,000	1,095,000,000
Southeastern	538,440,000	1,276,500,000
Lake Superior	3,510,000,000	72,030,000,000
Mississippi Valley	315,000,000	570,000,000
Rocky Mountain	57,760,000	120,665,000
Pacific Slope	68,950,000	23,905,000
Total, United States	4,788,150,000	75,116,070,000

In order to obtain any adequate idea of the valuable local data utilized in the Hayes estimate which is summarized above, reference must be made to the original report. At present it need only be said that little criticism can be directed against the details of the estimate, or against the comprehensiveness of the plan on which it was based. The point which does require attention is the distinction which Hayes made between "available" and "non-available" ore reserve. In the writer's opinion, the defect of the Hayes estimate arises from the fact that this distinction was not carried out on the same basis in the different districts. This matter will be taken up in more detail later, but at present it need only be said that Hayes' practice in this regard tends to increase his estimates of Lake ores and to decrease his estimates of southern ores. His "non-available" ores in the South include large tonnages which would be merchantable to-day; his "non-available" ores in the Lake region include

rocks of a type which will probably never be used in the iron furnace.

The Butler-Birkinbine Estimate of 1909.—During 1909, but after the publication of the Hayes estimate which has just been discussed, a very interesting estimate appeared in a brief filed before the Senate Finance Committee by Mr. Joseph G. Butler, Jr. The brief covered the entire question of the iron-ore situation in the United States, and brings up a number of considerations overlooked in previous estimates. In this report Mr. Butler was assisted by Mr. John Birkinbine.

This estimate gives, as the total tonnage of iron ores of present commercial standard available in the immediate future, the following figures for the various districts:

Area	Tons
Lake Superior region	1,618,000,000
Southern States	1,814,940,000
New York	750,000,000
New Jersey	135,000,000
Pennsylvania	45,000,000
Rocky Mountain region	100,000,000
Total available, United States	4,462,940,000

On comparison of the Butler-Birkinbine and the Hayes estimates, it will be seen that they agree closely in their figures for total available ore, the two totals being 4,462,940,000 and 4,788,150,000 tons respectively. In the distribution of this total among the various districts, however, they differ widely. The Hayes estimate for the Lake region is cut in half, but his figures for the South and for the northeastern States are more than doubled. These changes seem to me to be entirely in line with the facts of the case, so that in this respect the Butler-Birkinbine estimate may be considered to be a distinct advance upon all previous figures.

Revised Estimates, 1912.—In the estimate now to be presented, I have taken advantage of all the earlier work heretofore quoted, and have revised and re-arranged the results so as to accord with my personal experience and with recent work in various areas by others. The result is presented with some confidence, as representing at least a fair statement of the case, in the light of present knowledge.

In taking up the Lake Superior district we are struck at first by the wide variation between the estimates of various reputable authorities; but on considering their statements more carefully it will be found that the differences are more apparent than real, and that they are really differences of definition rather than of fact. The four important recent estimates give totals for the Lake region as follows:

Authority	Tons
Hayes	3,510,000,000
Van Hise and Leith	1,905,000,000
Butler-Birkinbine	1,618,000,000
Minnesota-Michigan Tax Commission	1,584,000,000

On examining the data on which estimates must be based, it appears that the Minnesota Tax Commission assesses the Mesaba and Vermillion ranges in that State as containing practically fourteen hundred million tons; and that the very able engineer who acted for the Michigan Tax Commissioners estimated the assessable tonnage on the Michigan ranges at practically two hundred million tons. There is, to start with, a universally accepted total amount of sixteen hundred million tons.

To this must be added the tonnage in certain ranges not considered in the above assessments; the possibilities of new tonnage in undeveloped territory; and the possibility that the assessed tonnages were themselves actually too low. With regard to the first point, tonnages must be added for Cuyuna range in Minnesota, the Baraboo and Clinton ores of Wisconsin; and the Wisconsin portions of the Menominee and Gogebic ranges. It is probable that no one would think of crediting this group with a total of less than one hundred million tons, and most estimates would probably run considerably higher. The definite Lake aggregate so far is therefore seventeen hundred million tons.

With regard to the two remaining features which will add to this total there is obviously large room for individual opinion. Finlay estimates that in addition to the assessed tonnages on the Michigan ranges, there are in all probability over one hundred and fifty million tons which these ranges will, in the aggregate, produce. In Minnesota we have to deal with the certainty that a system which taxes ore in the ground is not calculated to en-

courage exploration or development far in advance of actual requirements. And there is, of course, the further possibility of new discoveries in territory now unprospected.

Taking all of these facts into consideration, it is difficult to place the tonnage of strictly available ore of present-day commercial grade in the Lake region at less than two-thousand million tons; and it is probable that twenty-five hundred million tons would really be nearer to the truth. But for present purposes the lower figure can be accepted with absolute safety.

The available data regarding the ore reserves of the northeastern States are still very poor, so that there is room for wide difference of opinion here as to total tonnages. Newland has given detailed estimates of the Clinton ores of New York; but concerning the important magnetite deposits of the Adirondacks, the highlands of New York and New Jersey, and southeastern Pennsylvania, we have really very little reliable information. Descriptions of the geology of the various districts exist in profusion, but in most of these no attempt whatever has been made to give any consideration to the quantitative side of the matter. Under these circumstances Hayes' estimates for the northeastern States may be accepted tentatively as the best available at the moment, though it is hoped that better data will be in hand in the near future.

The Hayes figures for the available ores of this region are approximately three hundred million tons. This is certainly close to the *minimum* tonnage available; and at the present moment, until closer work has been done in some of the districts, we might assume that the *maximum* tonnage which we might expect would be perhaps six hundred million tons.

For the Rocky Mountain and Pacific States Hayes figures one hundred and twenty-six million tons of available ore. As our information stands now, this is almost certainly a heavy underestimate, for Utah alone would show a far heavier tonnage. With regard to the other western States data are scanty, and the range of estimate in this district must be wider than in other parts of the United States. For our present purposes it will not seriously affect the accuracy of the final results if we put the western States down for a minimum of three hundred million tons and a possible maximum of seven hundred million.

In making up his figures for the southeastern and Mississippi

Valley districts, here considered together as the southern district, Hayes certainly drew the line between available and non-available ores in a different way from that employed in his Lake estimates. The result is that the two sets of figures are not even remotely comparable. In order to put them on the same footing, it would be necessary to go over the data for each mining region in detail. Space is not available for these computations in the present chapter, but the final results may be presented briefly.

In the Hayes estimates, three of the southern districts suffered more severely than the others, being credited with far less than their minimum possible tonnages. These are (1) the Birmingham red-ore region, (2) the brown-ore area of northeast Texas and (3) the extensive brown-ore region reaching from northwest Alabama through middle and west Tennessee into Kentucky. In each case there were obvious reasons for the under-estimates. At the time Hayes prepared his report Texan ores seemed likely to be out of the market for many years to come; but recent freight arrangements will put them into eastern ports on a parity with Cuban ores of equal grade. In the Birmingham district there has been considerable recent development which enables us to count on far heavier tonnages.

Taking all of these facts into consideration, the figures given in the table below are probably justified in the light of existing knowledge as to conditions in the various districts. They are subject to change as more details can be secured. It is worthy of note, however, that such changes will almost inevitably be in the direction of raising the total minimum tonnage here counted on as available.

AMERICAN RESERVE TONNAGES

District	Range of estimate	
Lake Superior	2,000,000,000	2,500,000,000
Northeastern	300,000,000	600,000,000
Western	300,000,000	700,000,000
Birmingham	1,500,000,000	2,000,000,000
Texas	600,000,000	1,000,000,000
Other Southern	500,000,000	750,000,000
Total United States	5,200,000,000	7,550,000,000

The above estimates include only ores of present-day commercial grade—such ores as are now used during years of business

prosperity. They do not include the enormous reserves of very low-grade red ores in the South, or the low-grade siliceous ores of the Lake region.

The minimum figures, in each case, represent the lowest estimates which anyone, writing to-day, could possibly credit to the various districts. The higher figures represent the tonnages which may fairly be hoped for, and, are in my opinion, the closer to the truth.

Tributary Reserves.—It will be seen from the preceding discussion, that, to adopt an average figure, we can count on six and a half thousand million tons of American iron ore, before being compelled to accept a very startling decrease in grade. But the geographic distribution of this tonnage is such that, if there were no outside supplies, we would have to face very dear pig iron within comparatively few years. Fortunately the free importation of foreign ores will help out in this direction, though it will be seen later that the effect of lowering ore grades will be noticeable even with this aid.

In speaking of tributary ore reserves it is hardly fair to include the Spanish, Scandinavian and other Old World ores, for though some of them are imported heavily even now, they will ultimately be bought in competition with European furnaces which will need them worse than ours. The reserve tonnage which is, however, properly tributary to American furnaces, includes the ore deposits of Canada, Newfoundland, the West Indies, Venezuela, Brazil, and possibly Mexico. Other large ore reserves will almost certainly be uncovered in the Caribbean region, and possibly elsewhere to the south of us, but the reserves already known are sufficiently large to give a long lease of life to the American steel industry.

Some idea of the extent of the tonnage now available may be gained by considering that Spencer estimates that the Cuban brown-ore fields will yield three thousand million tons; and this is probably a very conservative statement of the matter. Other islands of the West Indies are known to carry similar ores, while bordering portions of the mainland show deposits of related type. The Brazilian iron-ore ranges are of the same order of magnitude as our own Lake ranges, while their ore grade is notably higher than the average now obtainable from the Lake. The ores of Canada do not give promise of being so extensive as those al-

ready mentioned, but the reserve tonnage of Newfoundland is still heavier.

Taking all of the known tributary ore fields into acoount, and making a very small additional allowance for extensions, it is probably well within limits to assume that there are six or seven thousand million tons of merchantable ore, in countries adjacent to the United States, which are more likely to be used in American furnaces than near the mines.

The United States has been an importer of iron ore for many years, but until 1879 the importations never amounted to over forty or fifty thousand tons annually. Since that date they have increased, though not steadily; but with the comparatively recent development of the ore fields on the north coast of Cuba the increase is becoming more marked. In 1910, for example, the importations amounted to nearly two million six hundred thousand tons, of which somewhat over half came from Cuba.

As the grade of our Lake shipments gradually decreases, the imported ores will naturally become of increasing importance to the American iron industry. Their importation and use will tend to keep the cost of manufacturing pig iron from rising as rapidly as it otherwise would. Imported ores will not be able to stop the trend toward higher manufacturing costs, but they will retard the process somewhat. There are no conceivable circumstances under which American furnaces will be able to make pig iron as cheaply as during the years of 1893–1897.

CHAPTER XXVII

THE PROBABLE DURATION OF AMERICAN RESERVES

Accepting the estimates of the present known ore reserves of the United States, given in the last chapter, as a basis for further discussion, it will be of interest to determine how these reserves compare with the draft that is being made on them now, and with the requirements which they are likely to have to meet within the next few decades.

The Draft on Our Reserves.—No detailed and accurate figures are available as to American iron-ore production prior to 1889, so that it is not possible to state directly the rate at which our iron ores have been drawn on in the past. But this defect can be remedied by using the data as to pig-iron production, which have been recorded steadily for sixty years, while earlier scattered records enable us to carry the figures back to 1800.

The following table has been prepared by me for use in this connection. The figures prior to 1854 are estimates made from scattered data. For the later years, the data are those collected annually by the American Iron and Steel Association, and may be accepted as final.

PRODUCTION OF PIG IRON, BY DECADES, 1800–1910

Decades	Long tons
1801–1810	500,000
1811–1820	350,000
1821–1830	1,000,000
1831–1840	2,300,000
1841–1850	4,945,000
1851–1860	6,818,737
1861–1870	11,366,963
1871–1880	24,055,278
1881–1890	56,902,041
1891–1900	98,124,754
1901–1910	211,321,934

On inspection of the preceding table it will be seen that the American production of pig iron has, on the average, somewhat

more than doubled in each decade. Of course there will be a point at which this rate of increase will be lowered, but at present

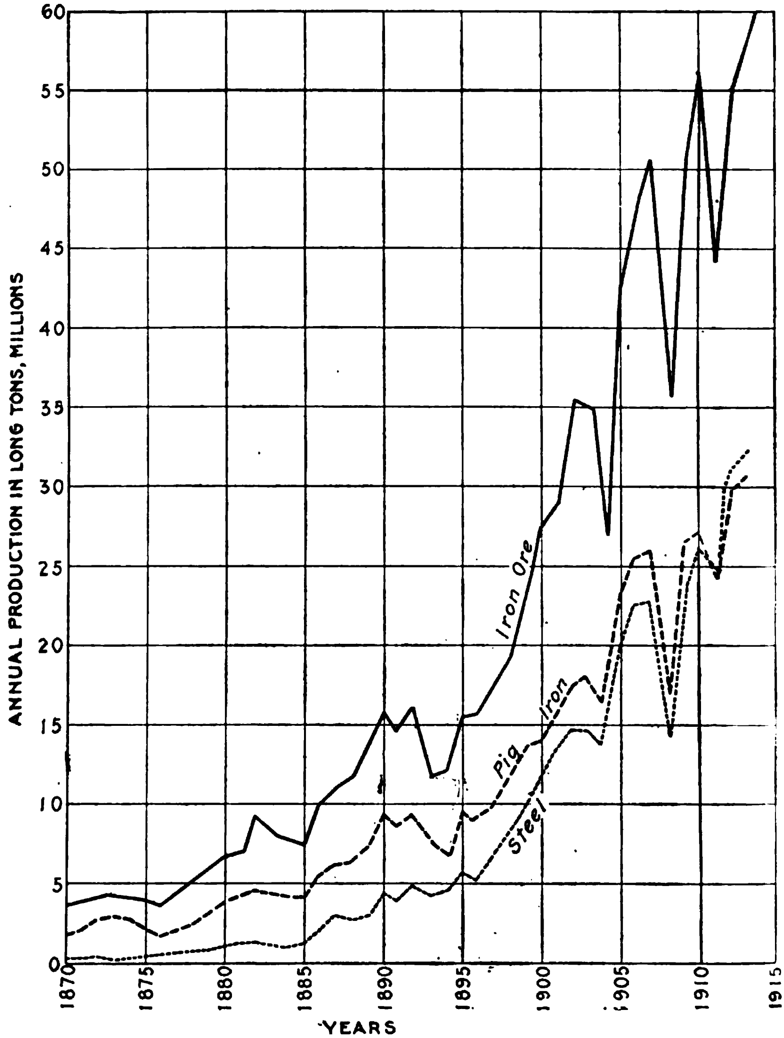

FIG. 63.

we must accept the possibility that it will continue for at least a few decades more. What this means in the way of iron-ore requirements can be estimated closely enough for our present

purpose by assuming that at present a ton of pig iron represents slightly over 2 tons of iron ore; and that the ratio of ore to pig is rising each year. Unless iron production slackens, it will therefore be necessary in the decade 1911–1920 to use about nine hundred million tons of ore; while the next decade will require close to two thousand million tons.

If this draft on our ore resources, great though it seems, were distributed evenly the results would not be industrially serious for several decades more. But since the bulk of the ore is at present drawn from one district, there is evidently some reason to give consideration to the matter.

The greatest strain, of course, will fall on the Lake Superior district, which now produces about four-fifths of all the iron ore used in the United States. If this proportion of the total output were to be maintained, the Lake ranges would have to ship about seven hundred million tons during the decade 1911–1920; and over sixteen hundred million tons during the ensuing ten years. That would make the total Lake shipments, from now to the year 1930, amount to over twenty-three hundred million tons; and as the total Lake reserves of present commercial grade have already been estimated at between two thousand and twenty-five hundred million tons, it will be seen that at this rate the present Lake reserves would not last much past the year 1930. Fortunately, though this calculation is precise enough arithmetically, there are other factors which will put off the exhaustion of the Lake reserves to a time further in the future.

APPARENT ANNUAL ORE CONSUMPTION

In an earlier chapter the tonnage of ore nominally available for consumption each year was calculated by adding together the domestic production and imports, and subtracting exports. The results, given in a table on page 186, are of some interest, particularly for comparison with similar statistics for European countries, calculated in the same manner by the British Board of Trade in its annual reports on the mining industry.

For our present purposes, however, it is necessary to arrive at a somewhat closer approximation to the ore tonnage actually smelted in the United States during each year. For a number of years past an estimate of this sort has been published by the

United States Geological Survey, in its annual volume on mineral statistics, and with the corrections noted later this estimate will serve for use now.

The official estimate may be expressed in a formula as follows:

$$A = (D + I + Z + SM' + SL') - (E + SM + SL)$$

In which A is the apparent annual ore consumption, D is the tonnage of ore mined in the United States in any given year, E and I respectively the exports and imports of ore for the same year, SM the stocks of ore held at mines at close of the year in question, and SM′ the stocks held at mines at the close of the previous year. SL is the stock held at Lower Lake ports at close of navigation of the year in question, and SL′ stocks similarly held the year before. Z is the tonnage of zinc residuum used at certain eastern iron furnaces. With this explanation the reader is in a position to check the figures given below, and to continue the table for later years if desirable.

The table which follows gives the basal data and the results of their use in the foregoing formula, for the years 1889 to 1912 inclusive. All the figures are taken from the Geological Survey publication already mentioned, with the exception of the 1911 and 1912 estimates. These have been re-calculated by the present writer, in order to bring them into conformity with the rest of the series. This change was necessary, because for 1911 and 1912 the official statistician introduced an entirely new basis of calculation, so that the official estimates for these years are in no way comparable with those of the earlier years.

The reader will understand, of course, that the results obtained by this method of calculation are not precise, for certain factors of more or less importance are omitted from the formula. There are no allowances, for example, for scrap, blue billy and other occasional ingredients of the charge, and no data available for estimating ore held in stock at furnaces over the close of the year. But with all its defects, the results have a certain comparative value, and the final average is doubtless close to the truth. It might be noted that during normal years the actual ore consumption would always be somewhat above that shown by the table, since most of the omitted factors are on the side of addition to the supply.

APPARENT ANNUAL ORE CONSUMPTION, 1889-1912

Year	Domestic iron ore produced *a*	Stocks of ore at mines	Stocks of ore at Lower Lake ports Dec. 1	Zinc residuum	Imports	Exports	Apparent consumption
1889	14.518,041	2,256,973	2,607,106	43,648	853,573	....	14,366,562
1890	16,036,043	2,000,000	3,893,487	48,560	1,246,830	....	16,302,025
1891	14,591,178	2,450,279	3,508,489	38,228	912,864	....	15,476,989
1892	16,296,666	2,911,740	4,149,451	31,859	806,585	....	16,032,687
1893	11,587,629	3,526,161	4,070,710	37,512	526,951	....	11,616,412
1894	11,879,679	3,236,198	4,834,247	26,981	167,307	....	11,600,393
1895	15,957,614	2,976,494	4,415,712	43,249	524,153	....	17,203,255
1896	16,005,449	3,405,302	4,954,984	44,953	682,806	....	15,765,128
1897	17,518,046	3,098,287	5,923,755	33,924	489,970	....	17,380,184
1898	19,433,716	2,846,457	5,136,407	48,502	187,208	....	20,708,604
1899	24,683,173	2,320,278	5,530,283	65,010	674,082	40,665	25,513,903
1900	27,553,161	3,709,950	5,904,670	87,110	897,831	51,460	26,722,583
1901	28,887,479	4,239,823	5,859,663	52,311	966,950	64,703	29,357,171
1902	35,554,135	3,834,717	7,074,254	65,246	1,165,470	88,445	35,886,921
1903	35,019,308	6,297,888	6,371,085	73,264	980,440	80,611	34,232,399
1904	27,644,330	4,666,931	5,763,399	68,189	487,613	213,865	30,224,910
1905	42,526,133	3,812,281	6,438,967	90,289	845,651	208,017	43,433,138
1906	47,749,728	3,281,789	6,252,455	93,461	1,060,390	265,240	49,355,343
1907	51,720,619	3,033,110	7,385,728	93,413	1,229,168	278,608	51,879,998
1908	35,983,336	6,065,397	8,441,533	110,225	776,898	309,099	32,473,268
1909	51,294,271	6,135,271	8,965,789	141,264	1,694,957	455,934	52,080,428
1910	57,014,906	9,422,285	9,426,881	137,173	2,591,031	748,875	55,246,129
1911	43,876,552	12,206,390	9,131,664	109,296	1,811,732	768,386	42,540,306
1912	55,150,147	10,241,287	9,497,168	104,670	2,104,576	1,195,742	57,763,250

APPARENT AVERAGE ORE GRADE

The table which has just been presented and discussed is of immediate service in attempting to determine the average grade of ore used in this country, and the changes which have taken place in this average.

For this purpose I have prepared an additional set of calculations, embodied in the table following. Here, using the apparent annual ore consumption as one factor, it has been compared annually with the pig-iron production of the same year.

At first glance the data presented in the table immediately preceding may seem too confused, as to trend, to give indications of much value for our present purpose, though even casual inspection will show that the average for the past decade must fall considerably below the average for the decade preceding.

The conditions are brought out more clearly, as usual, when the data are put in diagrammatic form, as in Fig. 64. The form of the curve shown in this diagram should be studied carefully,

APPARENT AVERAGE ORE GRADE, 1889–1912

Year	Apparent ore consumption, tons	Pig-iron output, tons	Apparent average ore grade
1889	14,366,562	7,603,642	52.91%
1890	16,302,025	9,202,703	56.50
1891	15,476,989	8,279,870	53.48
1892	16,032,687	9,157,000	57.14
1893	11,616,412	7,124,502	61.35
1894	11,600,393	6,657,388	57.47
1895	17,203,255	9,446,308	54.95
1896	15,765,128	8,623,127	54.64
1897	17,380,184	9,652,680	55.56
1898	20,708,604	11,773,934	56.82
1899	25,513,903	13,620,703	53.25
1900	26,722,583	13,789,242	51.55
1901	29,357,171	15,878,354	54.35
1902	35,886,921	17,821,307	49.75
1903	34,232,399	18,009,252	52.63
1904	30,224,910	16,497,033	54.64
1905	43,433,138	22,992,380	53.19
1906	49,355,343	25,307,191	51.28
1907	51,879,998	25,781,361	49.69
1908	32,473,268	15,936,018	49.07
1909	52,080,428	25,795,471	49.53
1910	55,246,129	27,303,567	49.42
1911	42,540,306	23,649,547	55.59
1912	57,763,250	29,726,937	51.46
1913	....	....	.....
1914	....	....	.....
1915	....	....	.....

bearing in mind at the same time the general condition of the iron industry in the different years covered by the figure. When this is done, it will be seen that the complex of figures in the table results from the action of several quite regular and distinct tendencies, which sometimes oppose each other and sometimes are cumulative in their effects.

Factors Determining Average Grade.—The fact is that the question of changing grade is not simple, but complex, and therefore the curve does not fall regularly with the years. Its form is, on the contrary, determined by a number of factors, of which the more important are:

1. The general condition of the iron industry. During hard times, when iron production is cut down to the minimum, ore prices are correspondingly low, and the grade of ore used is subject

to close scrutiny. During a period of low iron production, therefore, the average grade of ore used will be high. When prosperity is at hand, however, ore prices are high, and the furnaces will take almost anything that can reasonably be called ore. In a boom period, therefore, the average grade of ore will fall.

2. The discovery of new sources of ore supply. When a new high-grade ore district is discovered the tendency is for

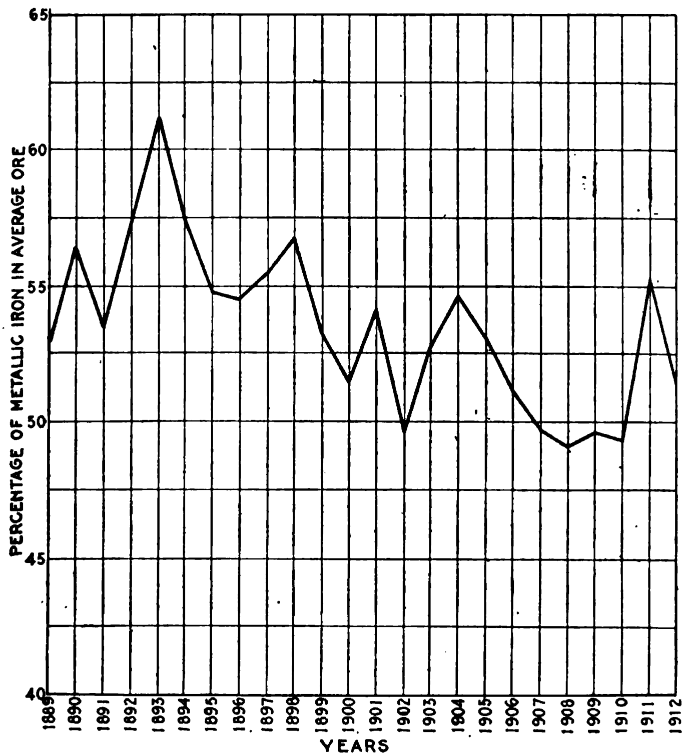

FIG. 64.—Changes in average ore grade, 1889–1912.

the average ore grade to rise sharply as the new product enters the market, and then to fall gradually but regularly when the new field begins to show signs of exhaustion. During the period covered by this table and diagram only one such important discovery was made, and the first heavy shipments from the Mesaba range carry the average for the year 1893 to the highest point on record.

3. General exhaustion of ore supplies. This factor, though overshadowed at times by the two preceding, is the one which must be the final cause of any regular decrease in average grade of ores. It would be important, even if the pig-iron production were constant, but it assumes much greater importance when an annually increasing demand for ore has to be allowed for.

The effect of these three main factors can be traced on the diagram with some distinctness. Our highest average was reached in 1893, when a fresh supply of high-grade ore reached the market during a period of low iron production. In this case the two factors had a cumulative effect. If the Mesaba had made its first heavy shipments during a boom year it would have tended to neutralize the temporary lowering of grade due to the boom.

When allowance is made for the varying condition of the iron trade in the different years, it must be said that the diagram seems to show a fairly regular decrease in ore grades for most of the period covered by it. From the high point of 1893, the progress downward was practically steady until 1911. That year, for the first time, showed a rise in grade more than could have been anticipated. It remains to be seen, however, whether or not this interruption to the general course of events was more than temporary.

The Future Course of Ore Grades.—So far as our domestic supplies of iron ore are concerned, the factors which bear upon this problem are sufficiently well defined as to admit of little error in outlining the probable future course of ore grades. With regard to imported ores the case is different, for here we are dealing apparently with an early stage in a movement whose final limits can not well be set. In discussing the course which average ore grades will probably take in the future, it is therefore advisable to consider first the conditions as to domestic supply, and then make some attempt to outline the probabilities as regards imported ores.

The Lake Superior ores, which now are the mainstay of the American iron industry, are showing a fairly steady decrease in grade from year to year. The falling off in the average grade of the Lake ores, over the past ten or fifteen years, has been about one-half of 1 percent a year. Part of this decrease is necessary while part is due to intentional use of lower grades during years of large shipment. Conservation of the total supply by such in-

termixture of low-grade ores is commercialy possible only for such companies as operate on a large scale and with the expectation of remaining in the business for many years to come. The small independent producer, in this as in other industries, is forced to operate uneconomically, and to ship his best ore each year, regardless of prices or business conditions.

If the Lake Superior district were the sole source of supply, it could be assumed with fair safety that the average grade would decrease slowly but steadily for some years to come; that the heavy reserves of ore in the neighborhood of 45 percent iron would hold the average around that point for a long period of years; and that between 40 and 35 percent the demand could be met almost indefinitely without causing further decrease in grade. If the Lake Superior average grade reached 45 percent, therefore, its further downward progress would be very slow; and at 40 percent or somewhat less the decrease would be checked for a great number of years.

Considering our southern supplies in similar detached fashion, it may be assumed that the average red ore today is little if any above 36 percent iron. Of course, being limey ores, these 36 percent red ores would rank commercially far above siliceous Lake ores of equal iron grade. Without attempting a precise comparison, it may perhaps be assumed for present purposes that they are technically equivalent to a Lake ore carrying 45 to 47 percent iron. The fact of interest, however, is that there are very heavy reserve tonnages of this 36 percent grade available, as compared with either the present southern rate of ore consumption, or with any future rate which seems probable. The decrease in average southern grade will therefore be very slow, and if in time the demand justifies the use of 30 percent ore, the reserves of this grade available are sufficient practically to stop any further decrease.

A third source of supply that seems to be just on the verge of becoming a more important factor in the situation is the magnetite reserve in the eastern and southern states. Apparently a slight further decrease in average grade of the Lake ore will open the way for marketing large tonnages of magnetic ores, in addition to the amounts which are now annually used in eastern furnaces.

In the preceding sections the possibilities of the Lake hematites,

the Southern red ores and the Eastern magnetites have been separately considered. It is now possible, still disregarding the question of imported ores, to group these results and obtain some idea as to the domestic ore situation. The matter might be summarized by saying that if domestic ore supplies furnished all the ore used in American furnaces, grade would probably decrease slowly until 45 percent is reached; that its further decrease to 40 percent would be very slow, owing to the large Lake tonnages available at this level, to the relative slow fall in southern grade, and to the increasing use of magnetic ores. Below 40 percent the decrease would be so slow as to be hardly noticeable, until the domestic reserves were entirely exhausted. If the Lake district ever gets down to a 37 percent average, the South would be running on 30 percent ore; and the average for the country might be 35 percent or thereabouts.

Heretofore our attention has been confined, for the sake of clearness, to the domestic ore situation; but this is obviously a very limited view of the case, though it has been the favorite of the conservation enthusiasts. As soon as the question of ore imports is considered, it will be seen that the entire status of the matter is changed. This is due to the fact that we have at our doors, in territory within the political and industrial sphere of the United States, ore reserves so immense as to dwarf our own domestic supplies. For our present purposes attention can be limited to the ore fields now developed along the north coast of Cuba, though as elsewhere stated there are good reasons for supposing that the ores now known constitute only a fraction of the total tonnage that will ultimately be found available in that general region. Newfoundland, Africa, Brazil and Europe are equally unnecessary in the present discussion.

Even if we limit attention to the Cuban brown ores, we have to deal with a reserve aggregating at least three thousand million tons of ore grading after concentration from 50 to perhaps 55 percent iron. This can be mined, treated, and placed in the United States at a reasonable figure. The relation of these ores to the domestic supply can be summarized about as follows: At the present day steel plants, located along the coast anywhere between New York City and Brunswick, Ga., could use Cuban ores profitably as compared with any possible large-scale domestic supply. Assuming that there are no serious changes in

tariffs, water rates, or rail rates, it seems probable that before the average Lake ore grade fell to 45 percent it would be profitable to run Pittsburgh furnaces on imported ore. This of course would involve a great decrease in the rate at which our domestic reserves will be drawn on, and a corresponding decrease in the rate at which our average grade will fall.

The Effect on Pig-iron Costs.—As the grade of the average furnace ore gradually lowers, an increase in pig-iron costs necessarily accompanies the decreased grade. It is true that advances in technology or decreases in labor costs may operate in the contrary direction, but savings made in this way will be negligible compared with the other increases in expenses.

Lowered grade of ore means not only an increased consumption of ore, fuel, and flux per ton of pig iron, but an increase in labor, relining and overhead costs (per ton of pig) due to decreased output per day. In addition, as the ore grade lowers, it is probable that the price of ore *per unit of iron* will rise; and the price of coke will show the same tendency. These latter factors cannot be valued closely, but the increases due to increased consumption of ore, fuel and flux are definite enough. Dealing with ores of the grades now under consideration, with Pittsburgh conditions as to grade of flux and coke, a decrease of 5 percent in the iron content of the ore involves the *additional* use of about 0.17 tons of ore, 0.12 tons of coke, and 0.36 tons of fluxing stone per ton of pig iron produced.

Using the data last noted, and inserting approximate current prices for the three raw materials, it will be found that a drop in ore grade from 50 percent to 45 percent implies an increase in cost, for raw materials alone, of about $1.25 per ton of pig iron. When the other elements of cost, which also increase as ore grade lowers, are considered, the total increase becomes still more serious. In addition, it must be borne in mind that the cost of coke per ton, labor per day, and iron ore per unit, are likely to increase in the future.

It is impossible to put a fair value on all of these elements of increased cost, but from those which are definitely known it seems safe to conclude that the cost of pig iron will increase at the rate of between twenty-five and fifty cents per ton, for each decrease of 1 percent in the average iron content of the ores to be used. In an earlier section of this chapter it has been shown that he

average grade has decreased almost one-half of 1 percent a year, during the past twenty years or so.

If we could assume that this decrease in average grade would continue, it would be necessary to accept the fact that as a consequence of the fall in average ore grade, there would be a correspondingly steady and marked increase in the cost of making pig iron. But we can hardly go as far as this with safety, for there are two elements which will operate to interfere with a future decrease in ore grades. First, there is the probability that in future larger tonnages of Lake ore will be subjected to drying or to concentration prior to shipment, and this will tend to raise or to maintain the average grade of the shipments from the Lake Superior region. Second, and still more important, there will be the restraining influence of imported, Adirondack and Texan ores, which will have to be reckoned with from now on.

CHAPTER XXVIII

OWNERSHIP AND CONTROL OF AMERICAN RESERVES

In preceding chapters the total extent and probable duration of the iron-ore reserves of the United States have been discussed in some detail. In this discussion the ore reserves were treated as purely physical bodies, and it was not necessary to refer in any way to their ownership. In the present chapter, however, these same ore reserves will be considered from an entirely different point of view, attention being concentrated upon this very matter of ownership. As will be noted later, there are two distinct questions which can be raised concerning the type and extent of ore-reserve ownership, and signs are not wanting that both of these questions will be brought up for decision in the near future. There is, first of all, the question whether private ownership of ore reserves has progressed to such an extent that it affords monopolistic advantages. Second to this in point of time, but not of importance, is the broader question whether private ownership is to be allowed under any circumstances. We may cover up these questions in more politic and more acceptable language, but after all they amount to this.

Stages in the Evolution of Opinion.—It will be seen that both the questions involved are of immediate interest and of great importance, not only to the iron industry, but to all American industrial development. The formulation of a proper public policy for dealing with control of raw materials and other natural resources must be preceded by careful study of all the factors which are concerned in the matter. If we are to retain our present system of entirely private control of such matters, the present status must be justified by proving that it is both equitable and efficient. For if it can be proven that private ownership leads to either injustice or inefficiency, some form of Government regulation will ultimately result. In either case the policy adopted, to be of permanent value, should be based upon the facts of the case, and not be accepted merely because it happens

to fit in with what seem to be the political or business requirements of the hour.

It is hardly necessary to recall that two very detailed investigations of the American steel industry have recently been made, by a Congressional Committee and by the Bureau of Corporations respectively; or that a suit for the dissolution of the United States Steel Corporation is now pending in the courts. The fact that these various investigations and suits have been prosecuted during the past few years is of advantage to a certain extent, for they have furnished a large selection of views and data from which to quote. But on the other hand, it involves the very serious disadvantage that the writer, in suggesting that one view of a controverted question seems more reasonable than another, may be considered to have the fate of one particular corporation in mind, and to be arguing the case as a partisan instead of stating the facts and probabilities fairly. This difficulty may as wel be recognized frankly, and the only possible reply to such criticism is to offer the discussion itself in proof, and to submit that it does not bear evidence of having been treated in a partisan spirit. As a matter of fact it may be noted that much of the data here presented had been prepared for use, in another form, some time before politicians discovered that iron ore could be made to yield publicity as well as pig iron.

In an earlier section, where discussion of the ore reserves of the United States was taken up, it was pointed out that until 1906 or thereabouts no one was particularly interested one way or another in the total quantity, probable duration, or ownership of our iron-ore reserves. It was known, of course, that some individuals and corporations owned more ore, or better ore, than others; but it was commonly assumed that this was due either to good fortune or to the exercise of better business judgment. It seems fair to say that, up to then, no one considered that there was anything unjust, either to competitors or to the public, in these conditions. The possibility that any one individual or corporation had secured or could secure ownership of all the iron ores of the country, or of any dangerous proportion of those ores, was not even dreamed of.

In 1906, however, an extremely pessimistic foreign estimate of America's ore resources reached the public eye, and became of interest in connection with an already well-formulated "Con-

servation Movement." This resulted in a second stage of public opinion regarding iron-ore supplies and their ownership.

The Conservation Viewpoint.—In order properly to understand the situation at this stage, it must be recalled that the conservation movement, at its inception and for some time after, was not concerned with the ownership of our various natural resources, but with their waste and exhaustion. Reasoning from conditions which undoubtedly existed in the lumber industry, it was perhaps too hastily assumed that a careful study of mining conditions would show that vast quantities of valuable minerals were being left in the mines or otherwise wasted. Soon after this, however, this idea was further developed into the view that, whatever might be the actual situation with regard to mining wastes, there was also need for careful study of the actual extent of some of the more important mineral supplies. Accordingly it was decided to secure as close an estimate as possible of the total available American reserves of iron and certain other metallic ores, of coal, oil and gas, and of phosphate rock. The reason for this particular selection of subjects will probably always remain a mystery, but the list omitted a number of mineral products whose supply is apparently limited, and on the other hand included some of unquestioned abundance.

This investigation of mineral resources was carried out by geologists detailed from the United States Geological Survey, and reports on the results of their work were later published by that organization. The work on iron ores had been placed in charge of Dr. C. W. Hayes, then chief geologist of the Survey, and his report is discussed in some detail in an earlier chapter. So far as we are here concerned with the matter, the Hayes report may be summarized as stating (1) that there is no serious avoidable waste in iron mining; (2) that the immediately available iron ores of the United States, of present commercial grade, aggregate almost five thousand million tons; (3) that, in addition, there are about seventy-five thousand million tons of ore, of lower grade or more poorly located, which will gradually become available as the better ores become exhausted; and (4) that certain reserves of high-grade ore, aggregating several thousand million tons, located in Cuba, Canada, and Newfoundland, must logically be considered a portion of the immediately available American

reserve, since they can be used most economically and profitably in the United States.

Impossibility of Actual Monopoly.—In Chapter XXVII it has been also pointed out that both our own immediately avail able reserves and the ore reserves in commercially tributary territory are in fact much larger than the Hayes report would imply. In any casual discussion of the matter it will be safe to assume that the available American reserve amounts to at least six or seven thousand million tons, and that the tributary tonnage is approximately as large.

At intervals there has been a good deal of rather indefinite talk about the existence or possibility of absolute monopoly in ore ownership. Consideration of the tonnages involved in the problem, as briefly stated above, will serve to show the great practical difficulties which would prevent the formation of an absolute monopoly, even were there no competitive purchasers or legal prohibitions to hinder attempts in this direction. At present, therefore, both the possibilities and the actual conditions in this line should be fairly well understood, and it is not probable that anyone who has paid much attention to the subject takes the possibility of absolute monopoly very seriously.

As to existing conditions, some idea can be gained by considering that even the largest existing steel company has not advanced very far in the direction of ore control. Estimates based on the official reports of the Minnesota and Michigan Tax Commissions credit the United States Steel Corporation with owning approximately 45 percent of the Lake ore reserves. In the South its holdings are far smaller, both relatively and absolutely, amounting probably to one-fifth or less of the total southern reserve; while in the western and northeastern ore districts it does not appear as a serious ore owner. For the entire United States, therefore, its proportion drops to perhaps one-quarter of the total; and if Cuba be included, to a far smaller fraction. As a matter of fact, the Pennsylvania Railroad Company, through its control of the Pennsylvania and Cambria Steel companies, is a very close second to the Steel Corporation in the matter of total ore tonnage owned, and far exceeds it if total ownership be compared with actual annual requirements. Many of the smaller companies have, in similar fashion, acquired far heavier ore holdings than the Steel Corporation, relative to their needs.

From any point of view, however, it is obvious enough that actual monopoly does not exist, and that it is not even dangerously approached. It will be later seen that, entirely irrespective of legal conditions, there are good business reasons for not attempting to secure it.

Present Status of the Discussion.—With the passing of the idea that it would be either feasible or profitable for one company to secure control of all, or almost all, of the American reserve of iron ore, the ground of discussion has been shifted. This shift has been so gradual, however, that even in discussing the subject we are hardly aware of the change. We still speak casually of attempted or threatened monopolies in ore holdings, while as a matter of fact we are really dealing with something quite different, and the arguments which would support or refute the old charges as to monopoly are valueless in treating the present phase of the discussion.

Under these circumstances, it is desirable to consider some of the points which are now brought into the field. In doing this it will be absolutely necessary to take cognizance of the various investigations which the United States Steel Corporation has undergone, at the hands of Government bureaus and Congressional committees, for in the course of these investigations all possible phases of the question have, at one time or another, been brought into view. It will not be necessary, however, to limit the present study to that particular corporation, for in order to be of any real value the conclusions reached must be of general application. Since practically all of the iron and steel manufacturing companies of the United States have followed the same general methods as regards acquisition, ownership, and valuation of ore reserves, it is possible to carry out this discussion without narrowing its scope to an individual instance.

Recent Views on Ore Ownership.—During recent years most of the opinions expressed on this subject have been by lawyers or politicians, rather than by engineers or manufacturers. It is obvious enough that this situation is not likely to result in a careful and impartial consideration of a rather complex technical problem, for neither the legal nor the political habit of mind is adapted to secure an adequate and fair presentation of a matter involving close reasoning from engineering and financial data. The acutely logical mind of the lawyer is often engaged in working

over a mass of very doubtful data, while the politician too often regards neither basal data nor logic.

The result is, that in discussing this subject, we have to deal with an extensive and variable mass of argument and opinion relative to ore ownership, some of which is distinctly worthy of attention, while much more can not be taken very seriously. In considering this great variety of opinion, selection of the views which seem to be important enough to justify further discussion is, of course, largely a matter of personal judgment. The principal views which have been seriously advanced within the past five or six years, regarding the monopolistic ownership or use of iron-ore reserves, seem to be those which may be briefly summarized as follows:

(1) That ownership of ore mines by steel companies is an abnormal and comparatively recent condition; and that the public interest would be best served if an absolutely independent set of mine owners sold ore to a distinct set of furnace men.

(2) That, though actual monopoly does not exist, some or all of the larger steel companies hold greater ore reserves than are demanded or justified by their actual requirements, as indicated by their present annual consumption of ore.

(3) That, though actual monopoly does not exist, there are not sufficient ore lands remaining in independent hands to permit the formation of a large new steel-manufacturing company.

(4) That, regardless of extent of ownership, the steel companies are in a position to earn excessive profits on their finished steel, because of assumed excessive valuations placed on their ore reserves.

In glancing over this group of summarized opinions, the reader will immediately note that, whatever their individual value, they are to some extent mutually contradictory. It would be difficult, for example, to accept simultaneously conclusions 1 and 4, for obviously the excessive valuations assumed in 4 would be more than counterbalanced by the new set of intermediate profits which would be introduced if 1 were accepted and followed. Similar contradictions occur elsewhere in the series, when the various arguments and views are critically examined, but in spite of this certain recent reports have managed to accept the entire series simultaneously.

Accepting the four views above summarized as representing,

for the moment at least, the most widely published opinions in criticism of the present status of ore ownership, it will be of interest to discuss in some detail the general principles by which the validity of the different views must be tested. It will be found, curiously enough, that many points which are commonly thought to be mere matters of opinion can, in reality, be determined with mathematical accuracy.

Of the four questions which have been raised, the first and second will be considered in the present chapter, as being most closely related to the subject of ore-reserve control. The third does not require detailed discussion, for the chapters devoted to description of the ore-producing districts of the United States will serve to suggest the possibility of increasing output and acquiring unworked properties in the different regions. The fourth question will be treated, incidentally to a discussion of ore reserve valuation, in a later chapter of this volume.

THE FUNDAMENTAL QUESTION OF OWNERSHIP

The view first cited brings us face to face with the broadest and most fundamental criticism that can possibly be brought against the existing status of ore ownership. It is of importance, not because of its inherent strength and soundness, but because of its basal character, and because of the dangerous remedies which it invokes.

This view, briefly stated, is that any ownership of ore mines or lands by iron or steel manufacturers is abnormal, and contrary to good public policy. It involves, as will be seen, a question of historic fact and a question of future policy. Taking up the first phase of the matter, it is notable that during some of the recent discussions of the steel industry, there became evident a curious misconception of the relations which have normally existed in the past between iron-ore mines and blast furnaces. The Chairman of the Stanley Committee, for example, frequently framed questions on the obvious assumption that ownership of mines by furnace interests dated back only to the advent of the large steel combinations—say to 1900 or thereabout. It was evidently taken for granted by Mr. Stanley, as well as by some of his associates on the committee, that during all the earlier periods of the history of the American iron industry, furnace

owners ordinarily bought their ore from an entirely independent set of mine owners. This erroneous assumption, unimportant in itself because it relates to a matter of purely historic interest, becomes of great importance as the argument is followed out, for it is used as a basis for conclusions of immediate and serious import. Assuming that ore ownership by furnace interests is a recent development in the industry, the conclusion drawn is that such ownership, in its present stage, is a step in the direction of final ore monopoly.

As a matter of historic fact, the assumption that mine and furnace have normally been separate enterprises could hardly be further from the truth. During all of the earlier periods of American iron history, the furnace owned and operated the mine, and was ordinarily located near it. In the south, east and west this business relation between the two has persisted uninterruptedly until the present day, so that over the greater portion of the United States merchant ore mines have never been of great importance. The Champlain and imported ores hardly qualify this statement.

Some light is thrown upon the views held on this point a century ago by the following quotation from Cooper,[1] writing on United States practice in 1813. "I have repeatedly met with persons who think that nothing more is necessary to render a place valuable for iron works than that there should be plenty of iron ore on it. But besides this, which ought to be at least a twenty years stock," * * * the author points out that many other things are requisite for profitable operation—markets, labor supply, charcoal lands, water power, etc. His suggestions along these lines are interesting, and might still be taken to heart by certain promoters. But our present interest is directed chiefly toward the evident assumption that the iron industry is based primarily upon the mine, and that the furnace was, at that date, merely a method of utilizing a mining property.

In the Lake Superior district, however, there was a relatively short period when the independent ore mine was the most important factor in the industry. This condition arose gradually, was due to peculiar local conditions, and seems to be passing. Since the conditions which caused it have disappeared, the merchant

[1] Emporium of Arts and Sciences, new series vol. 1, p. 18. Philadelphia, 1813.

mine is apparently on the way to becoming as scarce in the Lake region as it has always been elsewhere in the country.

At the commencement of mining in the Lake Superior iron district, the merchant mine was not contemplated, for all of the earlier enterprises were planned with the idea of making charcoal iron in the Lake region itself. Later, when the ore began to be shipped east, it is noteworthy that the very first shipments were to a furnace whose owners promptly secured the mine and commenced direct operation. As the mining area extended, however, and the older iron-producing centers became more and more dependent upon the Lake district for their ore supplies, the independent or merchant mine became a prominent factor in the industry, and remained so for thirty years or more. The eastern furnace men, confident that all their annual ore requirements could readily be filled in the open market, put their spare capital or new capital into additional smelting and finishing plants, as promising more immediate and larger profits than investments in mining lands.

Throughout all this period, however, there had always been mines operated directly by furnace interests, or controlled by them; and each period of depression in the iron business tended to decrease the relative importance of the merchant mines. In the eighties and early nineties this process became more marked, and long before the so-called "Trusts" were formed most of the larger iron and steel-manufacturing companies had mining interests in the Lake region. There is little to indicate that the later formation of the great industrial combinations had much effect, one way or the other, on the decline in merchant mining. It was, after all, merely a return to the conditions which had always existed in the other American iron-mining regions.

Effect of Independent Operation.—Nothing further need be said concerning the historical side of the matter, on which fortunately the record is sufficiently clear and decisive. Some consideration must be given, however, to the industrial features of the problem, in an attempt to determine, so far as possible, what form of mine ownership is likely to result in the maximum of economy and efficiency.

At present we are concerned chiefly in comparing the results attainable under independent or merchant ownership with those reached when the mines are controlled by the iron and steel

companies directly. It must not be overlooked, however, that a third possibility is either openly or implicitly put forward by some critics of the existing status. For the logical result of overthrowing this status would be, not to increase the importance of the merchant mine, but to introduce some form of Government regulation or operation. We may reasonably look forward to meeting, in the near future. arguments in favor of one of the following alternatives: (1) Government ownership of ore lands; (2) Government ownership and operation of sufficient mines and reserves to control the market; or (3) some form of Government regulation of ore prices. These possibilities may sound unreasonable, but they follow logically enough from a conclusion that operation of mines by steel companies is either inefficient or inequitable.

As to the facts in the case, direct evidence is difficult, and we can only judge from the comparative results attained in the past, at different mines and in different regions, under the two methods of operation. From this basis, the following conclusions seem to be justified.

(1) If all the iron and steel companies bought ore from independent mines in the open market, the fluctuations in ore prices would be wider than under present conditions. In prosperous years the mines would demand prices greater than they can now secure; in poor years they would sell ore at the cost of mining, without allowance for depreciation or amortization.

(2) Over a long series of years, including the usual proportion of good and bad periods, the price of ore would average notably higher than at present, for the mines when conducted as independent enterprises would expect a higher rate of profit than they are now credited with.

(3) So far as technical efficiency is concerned, that would not suffer if all of the mines, though independent of the steel companies, were in the hands of two or three large mining companies. But if the ownership of the mines were widely scattered, so that a number of relatively small mining companies existed, we might expect a marked decrease in efficiency. One result would be, almost certainly, that only high-grade ore would be shipped so long as it could be secured. This would cause an increase in the percentage of waste, and a shortening of the life of the ore reserves.

From the standpoint of either industrial efficiency or of the public interest, there seems therefore to be little to justify the criticism that independent ownership and operation of the mines would yield better results than are secured now.

THE LIMITATIONS OF RESERVE OWNERSHIP

The question next to be considered is whether the iron and steel companies have secured ore reserves so far in excess of their requirements as to justify the suspicion that the purchases were really monopolistic in intent, if not in effect. It is obvious that in order to settle this question it is first necessary to decide what the actual requirements of a modern steel company are, in the line of ore reserves. It will be found, on examination, that both their minimum requirements and their allowable maximum reserves are fixed by business considerations; and that both are clearly definable.

Minimum Permissible Reserves.—Taking up first the ore requirements of a modern steel company, it is to be noted that the *minimum* ore reserve which a steel-manufacturing company can safely carry is determined, and determined within rather close limits, by the amount of its investment in manufacturing plant and other fixed property. It would be obviously injudicious to risk a heavy investment which might be made entirely valueless within a few years by a shortage in ore supply. To be in a sound financial position, a steel company must therefore own sufficient ore to justify the erection of a steel plant of commercially competitive size, and to guarantee that this plant will be able to remain in operation on a competitive basis for a long period of years.

The length of the period whose ore supply should be made certain may, in fact, be fixed with some approach to accuracy. A modern steel company, making its own pig iron and steel, and selling a varied line of finished products, will necessarily have invested in plant and other fixed property somewhere in the neighborhood of forty to sixty dollars per ton of steel annually sold. These figures seem to be within the limits of the data presented recently in a report of the Bureau of Corporations, which certainly did not err in the direction of overcapitalization, and they may therefore be accepted as close to the possible *minimum* investment for which such a plant could be put together.

We may therefore assume that the average plant investment, excluding ore lands and working capital, is fifty dollars per ton of annual product. It is clear that if the profitable life of this plant is limited by the duration of its ore supply, a short-lived ore supply will necessarily mean that a heavy allowance must be made each year to cover the ultimate scrapping of the plant. However, this allowance may be handled in an accounting sense, it will in fact be a direct addition to the cost of producing each ton of steel. Disregarding for the moment the effect of interest charges to this account, it is roughly accurate to say that if the ore supply is only sufficient to last ten years, it adds five dollars per ton to the cost of producing steel; if the ore supply will last twenty-five years, this additional charge will be only two dollars per ton; if the ore will last fifty years, one dollar per ton of finished product will cover the final scrapping loss.

In reality, each of these figures would be decreased somewhat by interest credited to the sinking fund, but that fact does not seriously alter their relative importance, or affect the bearing of the present argument.

Industrially, it is evident that, other things being equal and merchant ore unobtainable, the relative duration of their two ore reserves will determine the competitive status of two steel companies. A company which must charge off five dollars per ton of steel in order to provide against a short-lived ore supply can not hope to compete with a rival whose charge to this account is only one dollar per ton.

It is obvious that there is a practical limit to the utility of this line of reasoning. The difference in the sinking-fund charge per ton decreases rapidly as the duration of the ore supply increases, and after a time becomes practically negligible. Taking this into account, it might perhaps be said that a modern steel company can hardly afford to have less than a twenty-five year supply of ore; that a larger supply would be even more economical; but that after a fifty or sixty year supply is secured the economy due to still longer life becomes too small to be important commercially.

Maximum Advisable Reserve.—It has been seen that the minimum ore reserve which a steel company can safely and economically provide is fixed, within quite definite limits, by purely business considerations. It is equally true, though it

seems to be less commonly understood, that the maximum reserve which it is economical or advisable for a company to own is also fixed by business considerations. That is to say, whatever the state of the law or of public sentiment on the subject, there is a point beyond which it is not *profitable* to go, in the way of owning large ore supplies. This point is fixed by the rapidity with which carrying charges—interest, taxes, etc.—accumulate on ore which is not used within a reasonable number of years after its purchase.

At this point it is necessary to call attention to the differences introduced by variations in the original cost of the ores. Obviously the carrying charges on a hundred-year supply of cheaply acquired ores will be less than on an equal supply of more expensive ores; but the full effect of this factor is rarely comprehended. If we recall that the average holdings of Lake Superior or northeastern ores may have cost the companies from twenty to fifty cents or more per ton, in the ground, while the average Cuban or southern ore reserve has perhaps cost from one-tenth of a cent to two or three cents per ton, it will be seen that the difference in carrying cost must be enormous. The result of this is that it is economically possible to carry far larger reserves of Cuban or southern ores than of the more expensive northern ores.

Data on Actual Reserves.—The following table presents specific data relative to some points which have just been discussed in a general way. In it will be found the total reserve-ore tonnage of a number of typical American iron and steel companies, and the present annual rate of ore consumption of these same companies. From these two sets of figures it is of course a mere matter of arithmetic to determine the approximate length of life of the ore reserve of each company, provided its average annual requirements do not increase. This they are of course likely to do, but we may for our present purposes assume that all of the companies will grow at about the same rate, so that the figures in the last column are in any case strictly comparable.

With regard to the sources of the data used, it may be said that the annual consumption given is either the exact or the approximate tonnage taken out during 1910, a record-breaking year so far as ore shipments were concerned. The reserve tonnages for the Steel Corporation in the Lake district are based on those reported by the Minnesota and Michigan Tax Commissions;

while its Alabama reserve (400,000,000 tons) is taken from reports by a number of engineers. The Republic reserves are quoted from annual reports of that company; and the Sloss figure from an appraisal report. The Pennsylvania and Bethelem data are from semi-official notices regarding the Cuban lands of the two companies. The Woodward figure is submitted by the present writer, and though calculated on a different basis from the other southern reserves, is close enough for our present use. The Dominion and Nova Scotia figures are estimates based on recent work, and are probably conservative, amazing though they may seem to anyone whose attention has been fixed on the Lake district. Taken as a whole, these estimates of reserve tonnage may be accepted as being fair, impartial, and as accurate as possible.

ORE HOLDINGS AND CONSUMPTION OF STEEL COMPANIES

Company	Ore district	Tonnage owned	Present annual draft	Duration of supply, years
United States Steel Corp....	Lake district.......	900,000,000	21,000,000	43
United States Steel Corp....	Lake and Alabama.	1,300,000,000	23,000,000	55
Pennsylvania Steel Co......	Cuba alone........	600,000,000	934,092	642
Republic Iron & Steel Co....	Alabama..........	89,000,000	700,000	127
Republic Iron & Steel Co....	Lake and Alabama.	128,000,000	2,000,000	64
Bethlehem Steel Co.........	Cuba alone........	250,000,000	318,814	783
Sloss-Sheffield Co...........	Alabama..........	78,000,000	800,000	95
Woodward Iron Co.........	Alabama red ores..	235,000,000	500,000	450
Dominion Steel Corp.......	Newfoundland.....	600,000,000	700,000	425
Nova Scotia Steel & Coal Co.	Newfoundland.....	2,000,000,000	600,000	3300

When the figures in the subjoined table are examined, and compared with the requirements as calculated in preceding sections, it will be seen that there is little reason to believe monopolistic intent has had much influence on ore-reserve purchases.

The companies whose chief holdings are in the Lake Superior district have really rather scanty reserves there. They would probably be glad to increase their holdings, but present prices for Lake ores in the ground are high, and the carrying charges would be heavy. The companies which have secured reserves in the south or in Cuba, where ore lands are still incomparably cheaper than in the Lake region, are subject to lighter carrying charges, and can therefore take on far heavier reserves without entering upon policies of doubtful economy.

The Industrial Effects of Overvaluation.—The factors which influence ore prices, and the methods and results of ore-reserve valuation have both been discussed in considerable detail elsewhere in this volume. In the present place there is no necessity to go over this ground again, but attention may be called to the conclusions which were reached—first, that most companies have rather undervalued than overvalued their ore reserves, from a strictly business point of view, and second, that no company has ever valued its reserves as high as their smelting or industrial value would justify. If these conclusions be generally accepted, there is little need to consider what effect overvaluation might have, provided it were practised. One fact, however, would seem to be obvious. That is, that unless all steel companies equally overvalued their ores, there could be no possible effect on prices. As a matter of fact, overvaluation by one or two companies, under any decent accounting system, would simply result in placing them at a distinct disadvantage in competition.

The Feasibility of New Competition.—Another phase of the subject may be touched on briefly, as being too irrelevant to be given much weight, though the argument has been recently advanced in all seriousness. Reference is made to the complaint that it would be impossible to build up a great new competing unit in the American steel industry, because our ore reserves are now so held that an adequate ore simply could not be secured by purchase from owners unconnected with the iron industry. Looked at impartially this seems to be about parallel with a complaint that a builder wishing to erect structures on Manhattan Island would not be able to secure the necessary land by purchase from an original Indian owner. So far as the statements about present ore ownership are concerned, it is very doubtful if they are based on accurate premises, but even if that were the case, the conclusion does not seem to be sound. If it were true that a new steel company would not be able to put together large ore holdings by purchase from small individual owners, the conditions would not be due to the intentional operations of the existing companies, but to our general system of private land ownership. A new arrival in any line of business can hardly hope to secure his site, his raw materials, his labor or his customers as cheaply as the competitors who were first on the ground; and there does not seem to be any good reason to single out the iron industry for

criticism in this respect. In closing this discussion it is well to point out that this particular line of criticism would become important only if it could be proven both (1) that it is impossible to secure adequate ore supplies for a new plant, on a reasonable basis, and (2) that if this is the case, the impossibility is due to deliberate attempt at monopoly on the part of the existing companies; for if the effect were purely incidental, due to a general shortage of ore supply, it could hardly be open to criticism. In the writer's opinion, neither of these conditions can be proven.

Whatever the hopes and expectations of 1901 may have been, time has shown that effective ore monopoly, on a tonnage basis, has not been attained. On the contrary, the most surprising feature of the iron industry has been the manner in which new and enormous reserves have been discovered and utilized. Cuba, Brazil, and Newfoundland are cases in point. Ten companies the size of the largest one now existing could get their reserve necessities satisfied in these new fields.

CHAPTER XXIX

THE IRON-ORE RESERVES OF THE WORLD

The principal known iron-ore deposits of the world have been described in certain preceding chapters (Chapters XVI to XXV) and in the course of the descriptions an attempt has been made to give some idea of their relative importance. In the present chapter this matter will be taken up in more detail, and so far as possible placed on a quantitative basis. It is of course obviously impossible that any one engineer should have a personal acquaintance with more than a fraction of the world's ore deposits, and under ordinary circumstances it would be impossible to hazard anything like a summary of the reserve tonnage of the world. But fortunately a recent publication has placed in convenient form the bulk of the statistical raw material required for such an estimate; and this will be used in the light of such knowledge as we have concerning its precision and accuracy.

In 1908 the Executive Committee of the 11th International Geologic Congress, planning for the meeting at Stockholm in 1910, asked various geologists for reports on the iron-ore resources of different countries with which they were familiar, with the design of securing a complete description of the known iron-ore resources of the world. These reports were published[1] in 1910, with a valuable prefatory summary by H. Sjögren.

World Estimates, I. G. C.—The statistics received by the International Geologic Congress were classified into three groups, according to the exactness with which the estimates had been made. In group A were included "such cases in which a reliable calculation of the extent of the deposit, based on actual investigations, has been carried on; group B includes those deposits in which only a very approximate estimate can be arrived at; and group C includes such deposits as can not be represented in

[1] The Iron-ore Resources of the World, two volumes and atlas. Published by the General Staff, Stockholm, 1910.

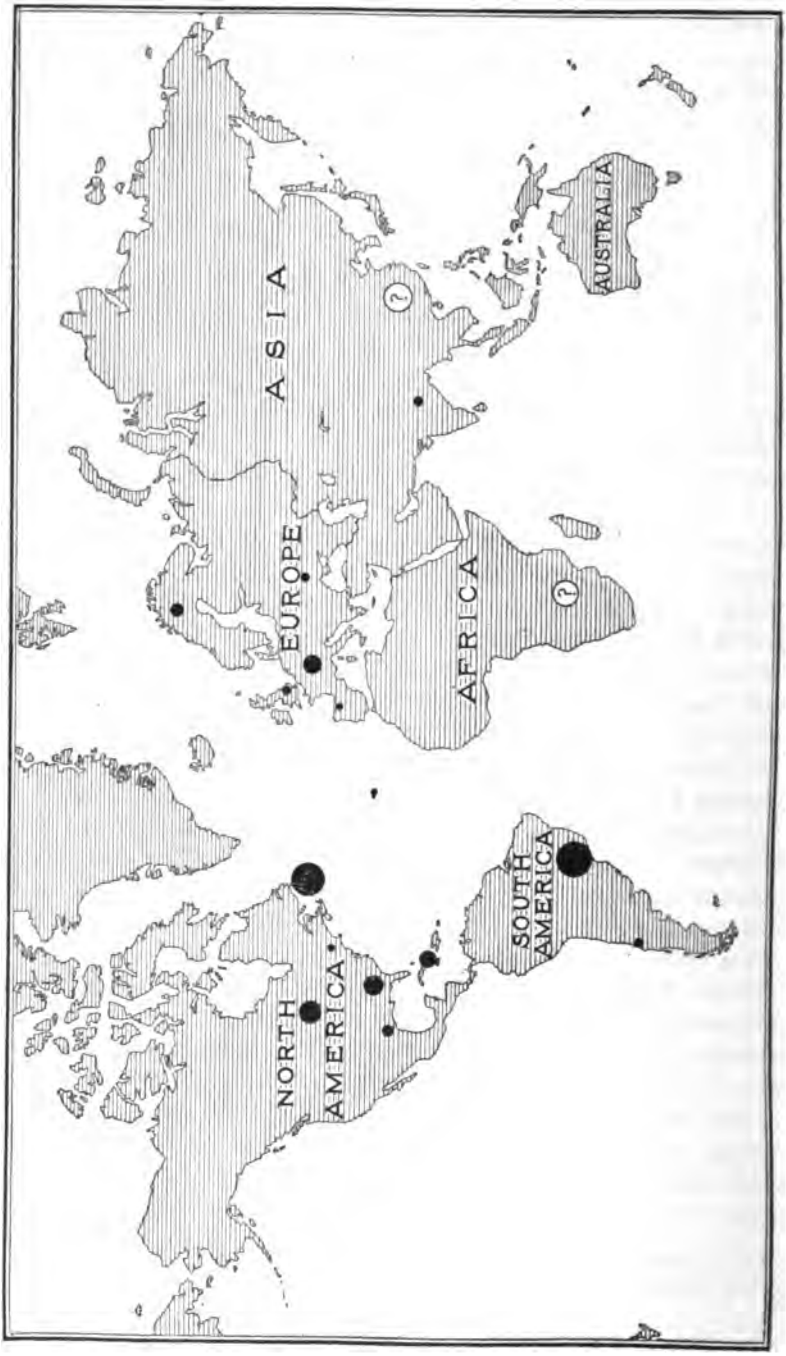

Fig. 65.—Chief iron-ore reserves of the world.

figures at all. The table below shows to what extent the reports received belong to one or the other of these groups"; and it also shows what portion of the earth's surface was not included at all in the inquiry, for one reason or another.

	Total area, in square kilometers	Area included in group A. sq. kilom.	Area included in group B. sq. kilom.	Area included in group C. sq. kilom.	Area not included in the inquiry. sq. kilom.
Europe......	9,724,321	9,063,725	260,333	166,520	233,743
America.....	38,323,629	7,851,470	10,689,348	17,605,631	2,177,183
Australia....	8,948,120	....	1,296,661	6,667,500	983,959
Asia.........	44,179,400	452,922	218,200	31,807,388	11,700,890
Africa.......	29,758,100	....	1,057,400	11,373,000	17,327,700
Totals......	130,933,570	17,368,117	13,521,942	67,620,039	32,423,472
Percent	100.00	13.3	10.3	51.6	24.8

As some guide to the extent of our present knowledge, it may be noted that the areas included in group A comprise practically all of Europe, the United States, Cuba and Japan; and that group B includes the Balkan States, Newfoundland, Brazil, Mexico, Algeria, Tunis, New South Wales, Victoria, Corea and New Zealand. Canada, Central America, all of South America except Brazil, and almost all of Asia, Australia and eastern Africa are included in group C. Much of China and Thibet, central and western Africa, and Alaska are among the utterly unknown regions not included in the inquiry. The effect of this limitation of existing knowledge on the actual distribution of probable ore reserves will be referred to again.

A further distinction was made in the individual reports, as to the probable commercial importance of the various ore fields. This distinction is difficult to make when only a few fields are compared; and it becomes increasingly difficult to maintain it when the scope of the inquiry is broadened to cover the entire world. In summarizing the reports Sjögren uses the terms "actual reserves" and "potential reserves" without definite explanation; but with a fairly steady line of division. The actual reserves seem to include the ore tonnages occurring in fields which are now being worked commercially; the potential reserves include unworked fields, and in a few instances, the lower grade or deeper ores of worked fields.

SUMMARY OF WORLD'S IRON-ORE RESERVES (SJÖGREN)

	Actual reserves		Potential reserves	
	Iron ores, metric tons	Metallic iron contained, metric tons	Iron ores, metric tons	Metallic iron contained, metric tons
Europe	12,032,000,000	4,733,000,000	41,029,000,000	12,085,000,000
America	9,855,000,000	5,154,000,000	81,822,000,000	40,731,000,000
Australia	136,000,000	74,000,000	69,000,000	37,000,000
Asia	260,000,000	156,000,000	457,000,000	283,000,000
Africa	125,000,000	75,000,000	Many billions	Many billions
World totals	22,408,000,000	10,192,000,000	123,377,000,000	53,136,000,000

Taken as a whole, the final report of the International Geologic Congress was fairly representative of the state of knowledge regarding iron-ore reserves at its date of issue, though there were wide differences in the value of different sections of the report. Even at the time of its publication, therefore, there were several points to which attention might profitably have been called; and the desirability of some further discussion of the subject has increased since then. There have of course been very obvious reasons against publishing any critical and detailed discussion of the question of ore reserves so long as that question was a matter of current political and legal importance, but with the progress of the dissolution suit these objections have disappeared.

In the following sections an attempt is made to summarize, in convenient form, the chief facts relative to the ore supplies of the world as they are now known, with particular reference to those of North America, South America and Europe, which are elements in the competitive steel industry of the world, as that industry is now developed. During the past few years, active exploration and development, by many different corporations and individuals, have greatly increased our knowledge of the iron-ore deposits of North and South America at least, and have made it possible to substitute somewhat more definite figures for certain of the less definite portions of the International report of 1910. The present discussion is offered as a suggestion along the lines which have been noted, rather than as a final analysis of the subject, for as will be seen there are still notable gaps even in our knowledge of the ore deposits of the two Americas; and with regard to Asia Africa and Australia the data are too incomplete to be more than suggestive. It will be understood, of course, that in preparing this summary I have made free use, not only of my own results

in the districts which I have studied, but of all available sources of information bearing on these and other districts.

ORE RESERVES OF NORTH AMERICA

In one of the preceding tables it is stated that the International estimate credited almost ten thousand million tons to North America. This total was made up as folllows:

Country or district	Ore tonnage
Newfoundland	3,635,000,000
Canada	no data
United States:	
Lake Superior	3,500,000,000
Clinton ores	505,300,000
Miscellaneous ores	252,500,000
Mexico	55,000,000
Cuba	1,903,000,000
Total, North America	9,850,800,000

The total reserve credited to the United States, something over four billion tons, was thus less than that determined by Hayes some years previously. The difference is largely due to the fact that in the International estimate no portion of the Texan or Adirondack tonnages are credited to actual reserves, all being placed in the class of potential reserves. The entire omission of Canadian ores from the estimate was due to lack of really definite data on the subject. The estimate given for the Clinton ores of the United States is far too low—one company alone owns as much as that; and a single mine property in the Russellville region will account for all of the 45 million tons credited to the "Mississippi Valley" region. On the other hand, the Lake figures are *relatively* too high though actually they may be low enough. The Newfoundland figure, curiously enough, though based on entirely incorrect data, is very close to later results in its total.

In view of later developments in some of the North American districts, and of the more exact information now available for others, it will be of interest to attempt an estimate on a more uniform basis than was possible several years ago. The data available regarding the ore deposits of the Lake Superior district have not changed materially, but in some of the other regions extensive prospecting and development work has given a far more definite basis for tonnage estimates than was at hand until recently. As will be seen, however, there are still numerous ore

districts and areas where the data for estimates are still too incomplete to allow more than a statement as to proven tonnage, and a guess as to possibilities. One of these practically unknown areas happens to be the country first to be discussed.

Dominion of Canada.—It is still difficult to make any estimate as to the iron-ore reserves of Canada, even in an approximate way. The known ore deposits of the Dominion are widely scattered over a very large area, and differ greatly in type. The intervening areas are, in many cases, little known.

At present, it can be said that any attempt to estimate the ore reserves must take account of certain tonnages of sedimentary hematite ores in Nova Scotia; of a group of fairly large magnetite deposits in New Brunswick; of a number of smaller scattered magnetite bodies in Quebec and eastern Ontario; of some developments in the Canadian portion of the Lake Superior district; and of a series of contact deposits along the Pacific coast.

Of the ores named, pretty close estimates can now be made for those in Nova Scotia, New Brunswick and British Columbia; while the Quebec and Ontario tonnages can not be approximated very closely. Taken as a whole, it is probable that even the most conservative figuring would credit the Dominion with about one hundred and fifty million tons of known and partly developed iron ores; while a more enthusiastic view of the Lake ranges might increase this estimate, heavily. For our present purposes, the lower figure named will be accepted.

Newfoundland.—In turning to the adjoining colony, we meet an entirely different situation, for Newfoundland possesses what is probably the largest ore tonnage in small area anywhere in the world. To add to its interest, this large reserve is almost entirely submarine.

The known and developed ores of Newfoundland are found in the southeast portion of the island, and occur as a series of sedimentary beds, in rocks of early Ordovician age. They agree in origin with our own Clinton or red ores, but are of somewhat earlier geologic age. About a dozen ore beds have been located and described in various reports, but three of these are workable. These three workable beds give an aggregate average thickness of ore of close to 30 feet. The ore is a very dense red hematite, grading 52 or over in iron, and the tonnage per square mile of ore territory is therefore very heavy.

The ore beds and their associated rocks occur in a trough or basin. The southwestern end of this trough outcrops on Bell Island, from which the rocks and ore beds dip northwardly under the waters of Conception bay. The accompanying sketch map will serve to give some idea of the surroundings and geology of the entire area involved in the question of reserve tonnages.

Geologic studies give reason to suppose that the ore beds continue northwardly, about as shown on the map. If we assume that they can be worked as far out as Cape St. Francis, the ore trough up to that point might contain some ten billion tons of ore. A certain portion of this area will be difficult to work; and in the worked portion heavy allowance must be made for ore left to support the roof. Discounting for these factors, we may fairly assume that the Wabana trough contains some four thousand million tons of recoverable ore. About half of this tonnage is controlled by the Nova Scotia Steel & Coal Co.

United States.—With regard to the iron-ore reserves of the United States, there are available a number of different recent estimates, differing little as to the facts of the case, but made on different bases as to grades and commercial conditions. An estimate which I prepared a year or so ago and which is given in detail in Chapter XXVII of the present volume seems to fit in best with our present purposes. It is as follows:

RESERVE TONNAGES, UNITED STATES

District	Minimum	Maximum
Lake Superior region	2,000,000,000	2,500,000,000
Southern red ores	1,500,000,000	2,000,000,000
Texas brown ores	600,000,000	1,000,000,000
Other southern ores	500,000,000	750,000,000
Northeastern states	300,000,000	600,000,000
Western states	300,000,000	700,000,000
Total U. S.	5,200,000,000	7,550,000,000

To this estimate as originally made, was added the note that it included only ores of present-day commercial grade—such ores as are now used during years of business prosperity. It does not include the enormous reserves of very low-grade red ore in the south, or the low-grade siliceous ores of the Lake region. The minimum figures in each case represent the lowest estimate which anyone, writing today, could possibly credit to the various districts. The higher figures represent the tonnages which may fairly be hoped for and are, in my opinion, the closer to the truth.

For the purposes of the present chapter, the maximum figures may be accepted tentatively. The Texas maximum might be decreased somewhat; on the other hand, some of the other southern ore tonnages might be increased.

Cuba.—The high-grade hematites which formed the original source of Cuban ore shipments are derived from a series of deposits on the south coast, near Santiago. These deposits are now estimated to contain, according to various engineers, a total of from five to eight million tons of ore. Similar ores occur elsewhere in Cuba, as well as in Porto Rico; but no large additional tonnage can be credited to them.

With regard to the brown-ore deposits which fringe the eastern portion of the north coast of Cuba, the situation as regards reserve tonnages is very different. These brown ores cover extensive areas, and the deposits are fairly regular in thickness, character, etc. Current estimates from various sources agree closely in placing the total known tonnage of crude ore at about three thousand million tons. This corresponds to approximately two thousand million tons of dried commercial ore, but in the present discussion the crude ore figures will be used and the necessary correction can be made by using also the crude ore average grade, say 35 percent natural.

Mexico, Etc.—From Mexico and Central America, we receive, at frequent intervals, very enthusiastic estimates of new or well-known iron-ore deposits. Unfortunately, when traced down, almost all of these Mexican and Central American iron ores appear to be found either as contact deposits or as ordinary gossan ores. In either case, tonnage estimates are likely to be made too high, owing to the excellent appearance which ore deposits of these types present at the surface. The tonnages actually known to exist in Mexico and Central America might perhaps be placed at fifty million at least; more optimistic estimates might run as high as one hundred million.

ORE RESERVES OF SOUTH AMERICA

In attempting to appraise the iron-ore reserves of South America, it is best to realize, at the outset, that enormous areas of that continent are still practically unknown, so far as their ore possibilities are concerned. On the other hand, there is very satisfactory knowledge of the reserve tonnages of certain limited

areas; and one of these areas happens to contain the largest known tonnage of high-grade ore in the world. Under these circumstances it is possible to summarize the existing state of knowledge with fairly definite results, even while admitting that there are obvious gaps in that knowledge.

For geological as well as geographical reasons, it would be advisable to separate the South American ores into three groups, but because of the various company interests involved, this will not be done at present. The ores of the north and west coasts will be grouped together; while those of the Brazilian area will be discussed separately.

Brazil.—The existence of large iron-ore deposits in Brazil has been known for many years, but it is only within the past few years that these deposits have given promise of becoming active factors in the ore industry of the world. Their grade and tonnage are such as to overcome disadvantages of location.

The Brazilian ores which require consideration at present are located in the state of Minas Geraes, and outcrop over extensive areas. They are hematites, high in iron and normally low in phosphorus. The deposits have been examined by many geologists and mining engineers—among whom may be mentioned Harder, Merriam, Chambers, Leith and Kilburn Scott; and there is substantial unity of opinion as to their main features.

As to origin, the Brazilian ores are regarded as sedimentary, occurring in original bedded deposits, with no trace of the secondary concentration which has been so effective in the Lake Superior region. As to tonnage, estimates by Merriam and Leith would justify the assumption that some 7500 billion tons of ore exist, of which perhaps half will grade over 64 or 65 percent metallic iron, and with phosphorus below the Bessemer limit. The remainder will grade between 55 and 65 percent iron.

The industrial significance of these figures as to grade and reserve tonnage requires little comment. The tonnage cited is three times that credited to the Lake Superior region; the average grade is that of ore which at one time existed on the lakes, but which has disappeared from circulation.

Venezuela, Chile, Etc.—It is highly probable that in future large deposits of residual brown ores, similar to those of the north coast of Cuba, will be located in South America, but at present the known ore deposits, outside those of Brazil, are of two differ-

ent types. In Chile, and for that matter all along the west coast of South America, there are a number of deposits of high-grade ores, often mixed magnetite and hematite, and apparently similar in origin and character to the contact deposits of Mexico and British Columbia. Some of the known deposits of Venezuela, on the other hand, appear to be more closely allied to the magnetite deposits of the Adirondacks and other portions of the eastern United States.

Taking the Venezuelan and Chilean deposits together, it seems probable that two hundred million tons would be a fair estimate of the ore which has been prospected and partly developed to date. There are, of course, large possibilities in excess of this tonnage, but on the other hand, some of the deposits are of a type whose tonnage it is particularly easy to overestimate. A maximum estimate, to cover probable development, might run as high as five hundred million tons for the ores of the northern and western portions of South America.

ORE RESERVES OF EUROPE

The International Report of 1910 contained very detailed descriptions of the iron-ore resources of each of the European countries, with estimates of their ore reserves, both actual and potential. It would be absurd for the present writer to attempt any revision of these estimates, and they will be accepted exactly as presented in the International report, so far as the tonnages are concerned. In order to facilitate reference, however, some rearrangement has been made with regard to the order and grouping of the various countries.

ORE RESERVES OF EUROPEAN COUNTRIES (REARRANGED FROM SJÖGREN). ALL QUANTITIES STATED IN MILLIONS OF METRIC TONS

	Actual reserves		Potential reserves	
	Iron ore	Metalic iron content	Iron ore	Metalic iron content
Germany and Luxembourg..	3878	1360	Considerable	Considerable
France..................	3300	1140	......	....
Norway and Sweden.......	1525	864	1723	630
Great Britain..............	1300	455	37,700	10,830
Russia (inc. Finland).......	865	387	1101	441
Spain and Portugal........	711	349	75	39
Austro-Hungary, Bosnia....	284	104	424	142
Greece....................	100	45	......	....
Belgium..................	62	25	......	....
Italy, Switzerland..........	8	4	4	2
Total Europe..............	12,032	4,733	over 41,000	over 12,000

THE WORLD'S IRON-ORE RESERVES

When we turn from the New World to the Old, we find that only one of the older continents has been sufficiently examined to permit even an approximate estimate of its iron-ore resources. In view of the scanty information available concerning the greater portions of Asia, Africa and Australia, it would be folly to add their small known reserves to the fairly well-determined reserves of Europe and the two Americas—and then call the result a world total. It will be far better to omit the three unknown continents from the total, in which case the result obtained will be substantially an estimate of that portion of the world's iron-ore reserve which is tributary to the Atlantic basin.

TOTAL KNOWN ORE RESERVES

Continent	Actual ore tonnage	Equiv't tons metallic iron
North America	14,760,000,000	6,455,000,000
South America	8,000,000,000	5,000,000,000
Europe	12,032,000,000	4,733,000,000
Total	34,792,000,000	16,188,000,000

We arrive, therefore, at the comfortable total of almost 35 billion tons of ore, equivalent to 16 billion tons of metallic iron, as being known to exist on three of the continents. All of this ore is of present-day commercial grade; and much of it is of Bessemer type.

As against this total known reserve of commercial ore, we may set the fact that the world is now making pig metal at the rate of some 65 million tons a year. On this basis, the known supply is sufficient to last over two hundred years more. If the world's ore requirements increase steadily in the future, there are still three unknown continents to draw from; and a vast tonnage of low-grade ores, not above considered, on the three continents which have been considered.

An actual ore scarcity can, therefore, hardly be taken seriously. On the other hand, as profits in the iron business decrease, the location of the various ore deposits becomes of far more importance than it has been in the past. Every ton of ore included in the preceding estimates can be mined, concentrated when necessary, and shipped to some large existing furnace district at a total cost of not over ten cents per unit. This is not an impossible figure for the furnaces to pay, and it means that the securing of

anything approaching a monopoly, on a tonnage basis, is impossible. But there are very large tonnages which can reach smelting centers at costs of four, or five, or six cents per unit—and these more favorably located ores will become of increasing relative importance as time goes on.

Probable Future Discoveries.—In estimating the known ore reserves of the world, it was noted that the data with regard to Asia, Africa and Australia are so fragmentary and incomplete that it was not worth while making use of them. There are obviously very great gaps in our knowledge of the iron-ore resources of the world, and it will be of interest to make some estimate as to the results which are likely to be attained when these gaps are filled—*i.e.*, when our knowledge of the ore reserves of Asia, Africa and Australia reaches the same degree of completeness as our present knowledge of the iron resources of the Americas and Europe. Thanks to a method suggested and used by Professor Sjögren, it is possible to do this with some degree of exactness. The Sjögren method will be followed, but it will be applied to the revised estimates of American tonnage which have been discussed in the earlier part of this chapter.

If we assume that the ore resources of Europe and of the two Americas are fairly well known now—and so far as commercially usable ores are concerned this is more nearly the case than is commonly thought—we can use this assumption as the basis for reasoning concerning the probable reserves of the three unknown continents.

This reasoning will involve the further assumption, which is correct enough for all practical purposes—that if very large land areas be compared, their iron-ore reserves are likely to be in proportion to the areas. It is clear that, given some knowledge of the geologic principles and causes which are involved in the formation of iron-ore deposits, we are warranted in extending our reasoning from the known to the unknown continents.

The ultimate basis for our work must be the following relations:

Continent	Reserve tonnage	Area, square miles	Tons per square mile
North America	14,760,000,000	8,626,000	1710
South America	8,000,000,000	6,837,000	1170
Europe	12,032,000,000	3,850,000	3140
Total and average	34,792,000,000	19,313,000	1790

The average for the three continents falls, it will be noted, at about the North American ton-mile factor. Assuming that this same figure will fairly represent the ore-bearing probabilities of the three unknown continents, we have the following results:

Continent	Area, square miles	Assumed ton-mile factor	Estimated probable reserve tonnage
Asia	17,256,000	1790	30,890,000,000
Africa	11,509,000	1790	20,600,000,000
Australia	2,947,000	1790	5,270,000,000
Total probable reserves unknown continents			56,760,000,000
Total reserves known continents			34,792,000,000
Probable world reserves, commercial ore			91,552,000,000

Of course this amazing total is merely an arithmetical quantity, and as such subject to any errors which may have been introduced in the data and assumptions employed. But it may fairly be assumed that it does, in this case, come as close to representing the real probabilities as to the world's total reserve of commercial ore as does any other method now available. Concerning the result itself, little need be said. It effectually disposes of some of the more hysterical statements which have been made about impending iron scarcity.

The Duration of the World's Ore Supplies.—In discussing the duration of American iron ore reserves (Chapter XXVIII), it has been noted that during the past decade the question of their possible early exhaustion has been brought to the front by a number of writers and legislators. In that chapter the matter was discussed solely as a local problem, but the general question of ore exhaustion can now be taken up in the light of the data presented on earlier pages of the present chapter.

In 1910 the entire iron-ore production of the world amounted, in round figures, to 142 million tons. The known supply of commercial ores is placed in an earlier table, at some 35,000 million tons; and I have noted that this is limited to three continents. The probable supply of commercial ores in the world has also been calculated above as about 91 thousand million tons. With these data in hand, as a basis, we may take up the probable duration of these deposits.

By reference to detailed statistics covering the past growth of the world's iron and steel industry, it will be found that for a

century the iron output has increased at a rate of slightly over 50 percent each decade. It may also be noted that in the opinion of the present writer this rate of growth is likely to continue for a few decades more. For our present purposes we might be safe in assuming that the pig-iron output and ore requirements of the world, during the next few decades, will be about as follows:

Year	Annual pig output, tons	Annual ore requirements, tons
1910	65,000,000	142,000,000
1920	100,000,000	250,000,000
1930	150,000,000	375,000,000
1940	200,000,000	500,000,000
1950	250,000,000	625,000,000

Using these figures, it will be seen that between 1910 and 1950 the total iron-ore requirements might reach the aggregate of 15,000 million tons. This is about one-half of the known ores of commercial grade; it is less than one-sixth of the probable ore tonnage of the world; and it would be an unimportant fraction of the ore that would be available if we lowered our standards much below present-day commercial grades.

The final conclusions which may be accepted as being derived from this study of the iron-ore reserves of the world are as follows:

1. Even admitting that the world's supply of pig iron will always be produced by charging relatively crude ores into a furnace, the supply of ore of strictly present-day commercial grade will last for considerably over a century.

2. If, without improving manufacturing or concentrating methods, we simply assume that pig iron will rise in price a few dollars—say an average of $20 per ton in place of an average of about $14 per ton—this rise in price will admit to use ten times as much ore as is now considered available.

3. But in speaking thus confidently of the world's supply of metal, we must not forget that local supplies will give out, even though a large total still remains elsewhere in the world. We may therefore expect great shifts in manufacturing centers to occur in the future, as they have in the past.

4. Coincident with the growing scarcity of local ore supplies in some countries now important in the iron industry will come changes in fuel conditions, in distribution of population, and in

market areas; all of which will aid in causing a redistribution of manufacturing centers.

Grade and Phosphorus Content.—Several points remain to be considered, bearing upon the amount of high-grade and of low-phosphorus ores available in the known ore reserves of the world. This is a matter of particular interest, and does not seem to have been summarized in the International report with sufficient allowance for recent developments. A table covering this matter, quoted from the report in question, follows:

CHIEF ORE RESERVES ORE 60 PERCENT IRON (1910 REPORT)

Country	Reserves high-grade ore
Russia	99,000,000
Sweden	1,095,000,000
Mexico	55,000,000
Cuba	3,000,000
Australia	49,000,000
Total world reserve	1,301,000,000

Concerning this question Sjögren remarks:

"From the table it is evident that about four-fifths of the known and recorded rich iron ores come in the deposits of northern Sweden. The high-grade ores, such as for example Kirunavaara, will therefore in future be very much in demand and the possession of such ore resources will form a decisive factor in the competition in the market of the world."

As opposed to this point of view, it may be suggested that the Brazilian ores, present in enormous tonnage, far outclass those of Scandinavia both in iron content and in their freedom from phosphorus. With a certain hesitancy, due to other factors, the same thing might be said of the Chilean ores.

Perhaps a fair statement of the case would be somewhat along the following lines. It is *not* true that ores suitable for the acid Bessemer and even the acid open-hearth processes are scarce; on the contrary they are now known to be very abundant. So far as quantity is concerned, there is no difficulty whatever. But we must admit that most of these very low-phosphorus ores are very inconveniently located, so far as existing or probable steel centers are concerned; and this means that ores for either acid Bessemer or acid open hearth are likely to be dearer in future

than they are now. As against this fact, we have to set the condition that, so far as one can judge, both the processes named are on the wane, relatively to other processes. The absolute *necessity* for a low-phosphorus ore is therefore disappearing, though its desirability still remains, in any normal basic open-hearth practice.

On the other side of the account is to be set the fact that the basic Bessemer process, which requires very high-phosphorus ores, has a far smaller visible supply than has the acid Bessemer. Newfoundland and Middlesboro supply an ore which is a shade low in phosphorus for good basic Bessemer practice; and the Lorraine region is the only one where cheapness and high phosphorus content go together. The only other possibility, the use of magnetites of extreme high-phosphorus type, does not offer much consolation so far as the chance of securing large tonnages at low cost is concerned. As the world's steel trade stands to-day, there would be more real interest in the discovery on any coast of a large ore-body carrying 2 percent phosphorus than in the discovery of a Bessemer ore-body.

The Possibility of Metallurgic Improvements.—The preceding discussion of the probable duration of the world's iron ore reserves is based on the assumption that the iron and steel to be produced in the future will be made in substantially the same manner as the bulk of the tonnage is now produced. It has been concluded that even on this assumption, the ore supply of the world is in no immediate danger of exhaustion. But there are always the possibilities that present processes will be greatly improved, or that entirely new processes will attain importance; and these possibilities require some consideration in the present connection.

In describing the operation of the blast furnace (pp. 142–148) it was said that the existing furnace is a very efficient machine, and that the possibilities of its improvement are comparatively small. All this is true enough, for the blast furnace does convert its charge into pig iron in a very economical way; and if we start with a given quantity and grade of ore and coke, it is probable that no more efficient way of converting the ore into pig can be found than by its smelting in a blast-furnace. But this very statement of the case indicates the inherent limitations of the present day process, and supplies a suggestion as to the possible changes which the future may bring forth. The blast furnace is

an efficient machine; but it requires a rather expensive source of heat and an ore charge of good grade. If, as may be the case at some points in the future, the fuels are low-grade and the ores are miserably poor, the blast furnace can hardly be expected to handle that kind of charge economically. It is under such conditions that entirely new metallurgical methods may be devised to meet the changed circumstances.

Usually, in discussing possible change in iron metallurgy, stress is laid on the possibility of using electric heat for the smelting of the ore, but it is always assumed that the ore to be used will be of substantially the same character and grade as that now charged into the blast furnace. In an earlier chapter some reasons were given for not expecting much from the electric furnace in the way of producing ordinary irons and steels under existing conditions; and under the conditions of our hypothetical future the electric furnace of itself will be even less effective.

What will be needed, in case the world ever gets down to using such low-iron and high-silica rocks as are sometimes discussed as possible future ores, will be a two-stage process. In the first stage, the natural iron silicate will be converted into a convenient iron salt—a sulphate, chloride, carbonate or oxide—and this iron salt will be freed from the silica and other impurities of the gangue. In the second stage the practically pure iron salt will be reduced to metallic iron—and the fact that slag will be absent will make a very simple form of electric or other furnace possible.

So much for the distant future, when as some authorities fear, our descendants will have to work rocks carrying 20 to 30 percent iron, and 40 to 50 percent silica. In the meantime, we may safely assume that for a long time to come the blast furnace will be an essential feature of iron metallurgy, and that our handling of ores will have to be adapted to its requirements and limitations. This implies that, as ore grades lower and ore prices increase, much better concentrating methods will have to be adopted. The furnaces of 1950 may be running on charges as good as the average of to-day, even though the average grade of ore mined will be far lower.

CHAPTER XXX

WORLD COMPETITION IN IRON AND STEEL

In earlier chapters the growth of the American iron and steel industries have been discussed in some detail, and in the course of this discussion reference was incidentally made to the rate at which the same industries had progressed in competing countries. In the present chapter this last matter can be taken up in more detail, and some idea given as to the growth of the world's iron and steel industries in the past, of the present status of world competition in those industries, and of the probable form which this competition is likely to take in the future. For we can not commit a greater error than by taking it for granted that the industries of the world have reached a fixed or stable condition; and on examining the bases on which these particular industries rest, it will be seen that the changes in relative importance are likely to be as serious in the future as they have been in the past. The nineteenth century saw the early development of the British iron trade to a commanding and apparently permanent leadership; but it later saw the growth of the American industries to a still more important position; and toward its close the remarkable growth of German manufactures. The twentieth century may in turn see the United States and Germany struggling for control of the world's markets in competition with Asiatic and perhaps African mills.

The Growth of the World's Iron Industry, 1800–1910.—The manner and degree in which the iron industry of the world has grown during the past century are well brought out by the table presented below. The data used in this table are of various degrees of accuracy, according to the dates and the countries. It may be assumed that prior to 1850 the figures, except for Great Britain, are merely fair approximations to the truth; that in later years the more general collection of official statistics gives us an increasingly firm basis for calculation; and that since 1870 the only reasonably important producer whose output is not definitely known is China. But for all practical purposes, even

after making allowances for the possible inaccuracies of the earlier years, the table may be accepted as close to the truth. It is, at all events, the first attempt to combine these data over a complete series of years.

PIG-IRON PRODUCTION OF THE WORLD, 1800–1911.
QUANTITIES GIVEN IN MILLIONS OF TONS

	United States	Germany and Luxembourg	Great Britain	France	Russia	Austro-Hungary	Belgium	Canada	Sweden	Spain	Italy	Other countries	Total world output
1800	0.06	0.02	0.20	0.06	0.04	0.01	0.02	.....	0.02	.....	.....	0.05	0.48
1810	0.06	0.03	0.27	0.09	0.07	0.02	0.03	.....	0.03	.....	.....	0.06	0.66
1820	0.02	0.04	0.40	0.14	0.10	0.03	0.04	.....	0.03	.....	.....	0.08	0.88
1830	0.16	0.08	0.68	0.27	0.18	0.04	0.06	.....	0.04	.....	.....	0.10	1.61
1840	0.29	0.15	1.40	0.35	0.19	0.06	0.10	.....	0.06	.....	.....	0.15	2.75
1850	0.56	0.25	2.35	0.41	0.23	0.10	0.14	.....	0.09	.....	.....	0.20	4.33
1860	0.82	0.60	3.83	0.90	0.34	0.18	0.32	.....	0.19	.....	.....	0.25	7.43
1870	1.67	1.40	5.96	1.18	0.36	0.37	0.56	.....	0.30	.....	.....	0.35	12.15
1880	3.84	2.73	7.75	1.73	0.45	0.46	0.61	.....	0.41	0.09	0.02	0.40	18.49
1890	9.20	4.66	7.90	1.96	0.93	0.97	0.79	0.02	0.46	0.18	0.01	0.50	27.58
1900	13.79	8.38	8.96	2.67	2.85	1.43	1.00	0.09	0.52	0.09	.....	0.65	40.33
1910	27.30	14.56	10.01	3.97	2.98	2.01	1.82	0.71	0.59	0.37	0.21	0.60	65.13
1911	23.65	15.32	9.53	4.44	3.52	2.09	2.01	0.82	0.62	0.35	0.24	0.80	61.40

On examining the preceding table it will be seen that since 1900 seven countries have regularly produced over one million tons per year of pig iron, and that the combined output of these seven important producers now is about 97 percent of the total pig-iron production of the world. The seven are, in order of present output, the United States, Germany, Great Britain, France, Russia, Austro-Hungary, and Belgium. The three leaders alone produced in 1910 almost exactly four-fifths of the world's output.

But in addition to the plain facts which it offers as to past and present output, the table suggests several interesting lines of inquiry. It may be asked, for example, what the probabilities are as to the future rate of increase in this great industry, and what factors are likely to cause the first slow-down in rate of growth. Then again, taking another standpoint, it may be asked how the output of pig iron in any given area bears on its international relations, so far as competition in steel and finished products is concerned. In the present volume neither of these questions can be discussed at any great length, but their impor-

tance requires that at least brief consideration be given to them in turn.

The Rate of Growth of the Iron Industry.—The first of the questions suggested relates to the probable future rate of growth of the iron industry; and as a basis for hazarding a suggestion we must first examine the history of the past century as set forth in the preceding table.

When the production in each tenth year is summarized, and each total compared with that following, it is found that the relation shown is as follows:

RATE OF GROWTH OF THE IRON INDUSTRY, 1800–1910

Period	Rate of increase	Period	Rate of increase
1800–1810	37.5	1860–1870	76.9
1810–1820	33.3	1870–1880	52.2
1820–1830	82.8	1880–1890	49.1
1830–1840	70.8	1890–1900	46.2
1840–1850	57.4	1900–1910	61.5
1850–1860	71.6		

For the entire period since 1800, the average rate of increase *per decade* is 58.1 percent; for the last forty years, the rate is 52.3 percent. These two figures correspond closely enough to prevent us from assuming that the iron industry has already reached a stage where a distinct falling off in the rate of increase can be observed. Taken together, they would seem to justify the assumption that for a few more decades at least, the world's output of pig iron is likely to increase at the rate of about 50 percent every ten years. This would imply that in some prosperous year near 1820 we may fairly expect to see a world's production of one hundred million tons of pig iron; and that by 1830 an annual output of 150 million tons may be normal. The rate of increase here assumed is considerably below that at which the iron industries of certain countries have recently developed, but since it has been calculated on a broader basis, it is probably more reliable than if based on local growth.

So far we have been considering merely the matter of tonnage produced, in an attempt to make some estimate of its future growth. But a large local production of pig metal does not necessarily imply that a profitable market will be found for all of it, and some attention may therefore be profitably given to the matter of steel production, of home consumption and of exports.

Steel Production, Consumption and Exports.—Such data as are available concerning the steel production of the world are presented below. They are not given for the earlier years of the nineteenth century, for steel as a commercial metal did not really exist until the Bessemer and open-hearth processes had been perfected.

STEEL PRODUCTION OF THE WORLD, 1850–1911.
QUANTITIES GIVEN IN MILLIONS OF TONS

Year	United States	Germany	Great Britain	France	Russia	Austro-Hungary	Belgium	Canada	Italy	Sweden	Spain	Other countries	Total
1850	.....	......	......	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
1860	0.01	......	......	0.03	.....	.....	.....	.....	.....	.....	.....	.....	......
1870	0.07	0.13	......	0.09	.....	.....	.....	.....	.....	0.01	.....	.....	......
1880	1.25	0.66	1.38	0.39	0.31	.....	0.10	.....	.....	0.04	.....	0.30	4.43
1890	4.28	2.23	3.68	0.58	0.38	0.50	0.20	.....	0.11	0.17	0.07	0.05	12.25
1900	10.19	6.54	4.90	1.54	2.16	1.14	0.64	0.02	.....	0.29	.....	0.45	27.87
1910	26.09	13.48	6.47	3.36	3.48	2.12	1.91	0.73	0.72	0.46	0.38	0.35	59.55
1911	23.68	14.78	6.56	3.81	3.87	2.29	2.16	0.78	0.65	0.46	0.23	0.30	......

The steel data, of course, are not so exact as those relative to pig-iron production, for the different countries report output of steel on somewhat different bases. England and the United States, for example, report on the basis of total tonnage of ingots and castings produced; but some other countries report what is practically steel for sale, and in combining these two types of figures errors are of course introduced. On comparing the pig-iron and steel totals, it is perhaps close to the truth to estimate that, after allowances are made for scrap used, about four-fifths of all the pig iron produced is converted into steel.

It would be convenient if we could drop the inquiry at this stage, and assume that the competitive ability of each country was measured by its annual steel production; but unfortunately the matter is not so simple. Belgium, for example, which does not rank particularly high as a producer, has so small a home consumption that her tonnage available for export is relatively very heavy. There must also be considered the form in which the steel is exported, for it is obvious that there is more profit to the producing country in shipping highly finished material than in exporting ingots or bars. It is in fact very difficult to compare the various countries, in their competitive ability, on an equitable basis.

The following table throws some light on the exporting importance of the various countries. It is quoted from the annual statistical report of the French iron masters, and all of the figures are therefore in metric tons.

IRON AND STEEL EXPORTS OF LEADING NATIONS, 1896–1909

	Germany	Great Britain	Belgium	United States	France
1896	829,510	1,933,549	525,796	89,491	84,839
1897	768,176	1,955,405	542,375	230,101	100,079
1898	847,534	1,708,154	563,830	453,460	93,803
1899	777,181	1,797,367	534,464	479,991	83,863
1900	838,360	1,624,500	417,769	707,806	51,885
1901	1,410,534	1,577,070	473,155	493,277	95,821
1902	2,126,803	1,958,136	601,518	201,502	160,512
1903	2,199,984	1,970,718	738,810	146,912	234,131
1904	1,673,793	1,947,925	706,268	943,987	269,928
1905	1,983,732	2,176,297	834,946	843,898	304,485
1906	2,116,908	2,328,749	866,169	845,029	238,739
1907	1,995,206	2,457,671	877,778	790,875	298,184
1908	1,773,807	2,071,713	814,632	591,781	350,993
1909	1,935,215	1,937,034	958,489	775,151	300,455

The products included in the above table differ somewhat in each country but may fairly be summarized as covering ingots, bars, sheets, structural and railroad material and plates.

The Basal Factors in World Competition.—When the question of world competition is considered with regard to a bulky and cheap product such as iron, it is evident that certain factors might be of importance in connection with smaller industries can be entirely disregarded here, and that attention can be concentrated upon a few relatively important factors. For our present purposes we may conveniently summarize these under the following headings:

1. Coal supplies.
2. Ore supplies.
3. Market conditions.
4. Labor conditions.
5. Financial and political conditions.

Of the five factors named, two—coal and ore supplies—are fixed, so far as any particular area is concerned, though even here the progress of the industry may in future make available raw materials now considered unprofitable. The three remaining factors are based less upon natural conditions than upon human relations and are therefore subject to more or less rapid change. In dis-

cussing the question of iron production it is a common error to fix the attention too firmly on the natural factors, and to think only of the raw materials. As a matter of fact, though of course an iron industry can not develop anywhere without raw materials, the history of its growth in various countries shows that the human or shifting factors far outweigh in effect the natural or fixed ones.

So far as the subject of coal reserves enters into this question, it may be summarized with sufficient accuracy for our present purposes by grouping the coal producing countries roughly according to current estimates of their reserve tonnages. The United States and China would occupy the first group, each having probably over 1,000,000 *million* tons of unmined coal in reserve. The second group would comprise countries whose coal reserves are supposed to fall within the limits of 100,000 million and 500,000 million; and this group would include Germany, Great Britain, Canada and New South Wales. A third group would include countries whose reserves are less than 100,000 million tons; here would fall India, South Africa, Russia, France, Spain, Belgium, Austro-Hungary and many others. Finally we might note that the probable coal reserves of Japan, Mexico, Central America, South America, and much of Asia and Africa are almost negligible.

With regard to the question of iron-ore reserves, reference should be made both to the preceding chapter on the ore reserves of the world, and to the still earlier chapters dealing with the iron-ore resources of the individual countries. These chapters contain sufficient data on this subject to be serviceable in the present connection.

In the following summary an attempt is made to place the general facts regarding the coal and iron-ore reserves of the world in convenient form for our present purposes. With this in view, the principal countries are grouped in four classes, as regards ore-reserve tonnages, and these four are in turn subdivided into other groups based on coal-reserve tonnage. The final result is that there are sixteen possible sub-groups in which any country may be placed. By using the data on ore and coal reserves presented in this and preceding chapters, modified where necessary to suit our present requirements, the proper place of most of the important countries can be ascertained quite accurately.

The grouping here offered is, of course, not precise or final, for in addition to gaps in our knowledge of the ore and coal supplies of the Asiatic and African areas, there is the difficulty of using a few classes to express almost infinite gradations in ore and coal reserves. It is necessary, for example, to place in the same subgroup different countries whose reserves may in reality differ quite widely in importance. But with all these defects, the summary does succeed in presenting the general facts more clearly than has been done heretofore, and it offers a valuable check upon our current idea of the relative future importance of different areas. The numerals preceding the names of the individual countries show, it may be noted, the order in which they rank at present as iron producers.

SUMMARY OF WORLD'S COAL AND IRON-ORE RESERVE SITUATION

	Known available iron ore reserves			
	I. Ore reserves 2000 million tons or over	II. Ore reserves between 1,000 and 2000 million tons	III. Ore reserves between 200 and 1000 million tons	IV. Ore reserves less than 150 million tons
A. Coal reserves of over 700,000 million tons	AI [1] United States.	AII [10] China(?)	AIII	AIV
B. Coal reserves between 100,000 million and 500,000 million tons.	B I [2] Germany.	B II [3] Great Britain. [8] Canada.	B III [16] Australia.	B IV
C. Coal reserves between 10,000 million and 100,000 million tons.	C I [4] France.	C II [1] South Africa?	C III [5] Russia. [6] Austria. [14] British. India.	C IV [7] Belgium.
D. Coal reserves less than 10,000 million tons.	D I Brazil. Cuba. Newfoundland.	D II [9] Sweden.	D III [11] Spain. Chile.	D IV [12] Italy. Greece. [15] Mexico. [13] Japan.

The small figures indicate the present rank of the various countries in iron and steel production.

The World Competition of the Future.—An examination of the data which have been presented on the earlier pages of this chapter is sufficient to show that at present the leading steel producers of the world are the United States, Germany, and Great Britain; and that these three are still so closely matched so far as natural resources are concerned that even slight shifts in Government policy may be enough to give one a distinct advantage over the others. For the present, and for the immediate future, this is a fair view of the case. But the situation changes sharply when we attempt to get some idea of the probable conditions a few decades

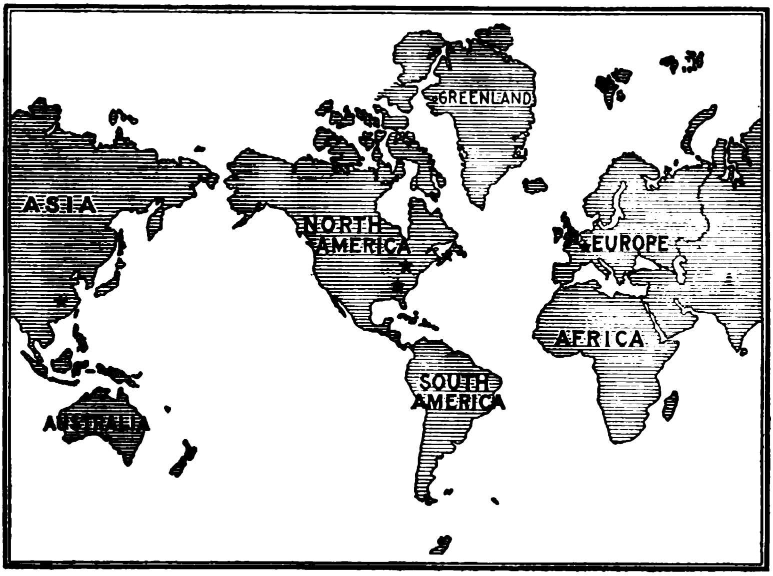

Fig. 66.—Chief competitive steel centers of the world.

hence, for by that time differences in natural resources will have begun to tell heavily against one of the competitors.

When coal and iron-ore resources, labor conditions and probable markets are all taken into account, it is difficult to escape from the conclusion that within a relatively short period, as the lives of nations are measured, the competition for leadership not only in steel but in general industries will lie between the United States, China and Germany. Even those who talk most loudly about the Yellow Peril do not seem to have realized the precise nature

of our disadvantage in the race struggle which is to come. When the East meets the West in final conflict, wherever and whenever that conflict may take place, it will be a case of full bunkers against exhausted ones; and no amount of courage or ingenuity will make up for deficiencies in coal supply. Fortunately, speaking from a purely national point of view, our own coal resources are so enormous that we can view this situation with some equanimity; but for Europe it is of more than passing moment.

The Limit of Iron and Steel Development.—In discussing the manner in which the world's output of iron has grown during the past, it was noted that for over a century, the increase in output has averaged about 50 percent every ten years. It was further pointed out that this rate of increase showed no signs of immediate diminution, and that if it is maintained it will imply the production of 100 million tons of iron in 1920, and of 150 million tons in 1930. If the same rate should persist to the end of the present century, the world's pig-iron output of the year 2000 would be approximately 2500 million tons. It is obvious that if we are to accept the possibilities that such tonnages will be required annually, we must also be prepared to admit the most dismal forebodings of the ultra-Conservationists; for in most discussions of the subject the final conclusion is that we will come to wreck because of the utter exhaustion of our ore and coal supplies. This is a discouraging conclusion, and it has little of practical value, for not even a political theorist has yet shown us how to eat our cake and have it too. So it may be of interest to discuss the question from a different standpoint, and see if any results of value can be obtained.

At the outset we may fairly assume that the iron production of the world will *not* maintain its present rate of increase forever; but that this rate will, at some period unknown, begin to fall off, so that instead of showing a 50 percent increase in output each decade, the increased production may be only trifling, and that ultimately there may be no increase at all. We know that this falling off must happen at some time; we do not know just when it will happen; but we do know that *when* it happens it will be due to the operation of one or more of the following three causes:

1. Actual decrease in the world's steel requirements.
2. The use of substitute materials for iron and steel.
3. Exhaustion of the ore and coal supplies.

It will be profitable to take up these three factors separately, in the order in which they have just been named, and try to determine how far each one is likely to exert a serious influence over the future of the steel industry.

1. *Decreased Demand.*—Though steel and iron are not imperishable, the amount which is lost to the world each year is a mere fraction of the annual supply, and this fraction is becoming relatively smaller each year. The chief loss is by rusting, though the more spectacular losses to which attention is called are through shipwrecks, mine disasters, etc. As the world goes on we may fairly expect that both these sources of loss will decrease, at least relatively to the annual supply. But this implies that the bulk of the year's output is added to a steadily increasing stock of iron and steel already in use; and obviously there must come a time when the stock on hand will be sufficient for all uses, with the help of comparatively slight additions and renewals. This may be accepted as a certainty of the future; and the only question then is, whether the slacking off in demand is likely to occur soon or at an indefinitely future day. Of course this question cannot be answered with any precision, but even a summary of the main facts bearing on it brings out some points of interest.

If we could confine attention to Europe and the United States, it could be said that both the annual output and the consumption have shown steady and large increases for many years; but that in spite of this fact there are certain features indicating that the turning point may be nearer than expected. There must be noted, for example, the fact that in certain lines the industry is not progressing as rapidly as heretofore; the rail-mill capacity of the United States, as an instance, is probably almost twice as great as the average annual requirements. And there is the far more important fact that the great producing nations have, during the past decade, been led to depend more and more upon the export trade, not only during years of depression at home, but in normal years. It is indeed very doubtful if the civilized portion of the world, confined to its own markets, could hold the 50 percent rate of increase for more than a decade longer.

But the outlook becomes more encouraging when the other parts of the world are recalled to mind. At present European and American mills supply the iron and steel requirements of a civilized area which contains about one-third of the inhabitants

of the globe. At first glance it might be assumed that the sudden modernization of the world would afford a market for about three times our present annual steel production. This, however, would be an error of the same type which is encountered when the western United States is compared, as a possible steel or cement market, with the east or middle west, on a purely population basis. Steel consumption is not entirely dependent on population; and large portions of the earth will never be as important consumers as Europe. If we had any exact data on the coal reserves of the world they might serve as a better basis of comparison than population. But since exactness is not required in the present discussion, it might perhaps be safely assumed that if the entire world could be suddenly modernized up to the standard of Europe and the United States, a market for between 125 and 175 million tons of steel per year could be found now.

This is somewhat more than double the present output of the world; but it is only about what the present rate of growth will produce by 1930. So that even on this basis, two decades more may see the beginning of a decreased rate of growth in the steel industry of the world. In an earlier chapter, where the duration of the world's iron supplies is considered, calculations have been made on this basis.

2. *Substitute Materials.*—The second possibility is that, even though the world's requirements for structural material continues to grow at the present rate, this demand may be partly or wholly satisfied by the use of some other metal or of some non-metallic material as a substitute for iron and steel. This is of course a possibility, and one that appeals strongly to popular writers on the subject. It is very easy to refer casually to the possibilities of electro-metallurgy, to call attention to the growth of the cement industry, and to mention the development of aluminum manufacture. But when we pass out of the domain of magazine writing and into the realm of facts, the solution offered does not seem so simple or so promising.

The inherent difficulty of the matter is brought out sharply as soon as we recall that an efficient substitute must be cheaper than the material for which it is substituted. This statement would be subject to exceptions, but in considering a large-scale industry it may be accepted as substantially true. More than that, when we are dealing with some hundreds of millions of tons

per year, it is clear that in order to be cheaper, the substitute material must be naturally very common. Now, if the reader will refer back to the tables in Chapter II, where analyses of the rocks of the earth's crust are presented, it will be seen that the only elements commoner than iron are silica and alumina, though lime and magnesia follow close behind. It is out of this group of four elements that our theoretical substitute for iron and steel must be manufactured. The substitute may be a metal, an oxide, or a silicate compound.

My views as to the possibility of securing a substitute for iron from this group are perhaps unorthodox, from a popular standpoint, but they have some basis in fact, and may as well be stated. It must be borne in mind that we are not dealing with unknown elements or compounds, but that all of the possible components of the group are very well known. We have already a very fair idea of the properties which may be expected from aluminum, silicon, silica, lime, magnesia, lime silicate, etc.; and in no case does there appear to be any serious chance that a product can be developed to take the place of any large portion of the world's iron requirements. Some of the theoretically possible materials can be dismissed with mere mention, and even the two best known—aluminum and Portland cement—do not seem promising. Any study of the resources and possibilities of the aluminum industry will lead to the conviction that this metal will become a very serious competitor for copper, that in time it may replace part of our tin-plate requirements, but that it is extremely unlikely that it will cut into the iron trade in any other way. As for cement, a rather intimate acquaintance with that industry leads me to consider cement not as a competitor to steel, but as a subsidiary material. Portland cement, as at present made and sold, does not seriously reduce the requirements for iron at any point, and in some ways tends rather to increase those requirements. It is of course possible that cement, as it may later be made and used in another form, may have more influence over the steel industry.

3. *Raw Material Exhaustion.*—It is a current idea that exhaustion of iron ore and coal reserves will occur so soon as to put a stop to the normal development of the iron industry. In the present study, as shown by the paragraphs relating to the decreased demand for iron, this conclusion, is not accepted. So far as such

a matter can be decided far in advance, it seems far more probable that the first slackening in our rate of growth will take place long before the ore and coal supplies of the world show signs of exhaustion; and that decreased demand will become effective long before we have to accept any substantial reduction from existing standards of ore grade. Much of this matter has been gone over in Chapter XXIX, where the probable duration of the world's ore supplies is discussed in some detail. Here it will only be necessary to summarize the main facts of the case.

No good estimate of the world's actually available coal supply is known to have been made, but a series of partial estimates will give a basis good enough for our present purposes. It may then be assumed that to meet the world's total future fuel requirements there are some four million million tons of real coal in known coal fields and at reasonable working depth. To this, for the more distant future, we might add very heavily for lignites and low-grade coals, for new fields, and for coal at depths now considered unworkable. At present the world is using this supply at the rate of some one thousand million tons per year. The coal supply will hardly give out at any early date, no matter how fast the demand increases; and as long as there is any commercial coal left, the iron industry will get its share of it.

As for the duration of the ore supply, that has already been discussed in sufficient detail in Chapter XXIX. Here it is only necessary to say that the world's supply of good ore will suffice all probable demands of the iron industry for a century or so more, even allowing a rate of increase which the present writer does not think likely to occur; while if we contemplate the use of lower-grade ores several centuries may elapse before the ore supply will be in serious danger, even assuming the same remarkable rate of growth in ore utilization as occurred during the nineteenth century.

CHAPTER XXXI

QUESTIONS OF PUBLIC POLICY

There remain to be considered certain questions regarding the relations which exist, and those which should exist, between the Government and the iron-mining industry. Some phases of these questions have been touched upon in the course of the chapter devoted to ore ownership in the United States, but a more general treatment of the subject seems advisable in the present place. There are, in addition, a number of contact-points between Government and private enterprise which may profitably be at least summarized here.

The Limits of State Interest.—For almost all of the nineteenth century, the public policy of both Great Britain and the United States was based, more or less explicitly upon purely individualistic theories of State action. Until within the past ten years any suggestion of active Government control or intervention in industrial affairs, except to insure justice between competitors, would have been looked upon as an idle theory, with no possibility of acceptance here. So far as mine control was concerned, no member of either political party would have dared to suggest anything more radical than that the Government might, perhaps, lease its mineral lands instead of giving them away. Thinking men always assumed that there was the possibility of future trouble dormant in the hard-coal situation, but that was looked upon as a special and very exceptional case.

With the conservation movement of 1906, however, we entered upon new ground. From that time on the change in popular sentiment has been very obvious, and of course our politicians have changed with it. To-day there is no hesitation about proposing Government control or actual ownership of any kind of property or industry; and there is as yet no sign that this movement is approaching its culmination.

Of course, if we accept the idea that all of our industries are to become socialized, there is no reason to interpose an argument

on behalf of any special industry or group of industries. Pure socialism is conceivable, but it is doubtful if any of our politicians are courageous enough to declare openly in favor of its adoption. On the other hand, if we are to stop at any point short of socialism, there must be some basis for deciding where that stop is to be made. Even a politician must think, occasionally, and attempt to supply some justification for his votes and actions.

Assuming that we are to have a Government of the type here called Progressive, and in England Liberal, we may allow for a considerable extension of State activities, provided they follow some recognizable and logical course. And, for our present purposes, it is well worth while attempting to determine what that course should be, as applied to the mining industries in particular. There will, I think, be substantial agreement as to some basal features, and violent disagreement as to some details of actual practice.

The Encouragement of Development.—One feature upon which there should be close agreement among all parties relates to the general attitude which the State should take toward industrial development. In the modern industrial State all the interests of the Government favor the most rapid possible development of natural resources, consonant with commercial profit. As applied to the mineral industries this attitude involves two distinct phases of Governmental activity.

First, there should be a reasonable inducement or encouragement for active search for new mineral deposits. Such encouragement would primarily take the form of offering the discoverer a reward for successful effort. This reward would naturally include a free or cheap title to the discovery, whether that title be fee simple or leasehold. The reward would become more certain if the title be clear, definite, and free from the probability of vexatious and expensive litigation. Unless private exploration is to be rewarded in this fashion, the Government must be prepared to undertake both search and development itself, and past history does not justify much hope in this regard.

Second, there should on the other hand be some requirements that development should be carried on as rapidly as commercial conditions justify. This may be secured by a sliding scale lease, the rental increasing annually; or by revocation of title in case actual shipments have not taken place within a certain number of

years after discovery. But since it is commonly to the interest of the owner to prosecute work as rapidly as possible, all such requirements should be so drawn as to give him the benefit of the doubt, and merely be designed to protect the State from intentional pocketing of ore reserves. This brings us, naturally, to another phase of the relations of the State to mining industries.

The Prevention of Monopoly.—The State has, of course, an interest in seeing that the mineral properties which it gives, sells, or leases are not used as the basis for extortionate prices on the part of the new owners; and it is justified in taking proper steps to insure that monopoly of raw materials be prevented. On this point there is probably general agreement, but there is wide difference of opinion as to the actual facts in any given case, and as to the preventive or remedial action to be taken.

During the past decade, for example, there have at various times been charges that certain raw materials were being acquired on a monopolistic scale by one or more corporations. Among the mineral raw materials so discussed may be named iron ore, coking coal, aluminium ore, anthracite coal, and a few minor products. On the assumption that such monopoly existed, there has been a widespread demand for restriction of ownership to some definite percentage of the total supply. This has involved certain errors as to the facts of ownership, and more important errors as to the feasibility and effects of extensive ownership.

In reality there are very few mineral materials which could be completely monopolized in ownership at any reasonable cost. Diamonds are, as we know, subject to highly artificial price regulation; and potash and nitrates are held in what is substantially a Government-aided monopoly. A few minor products are controlled quite completely by either producers or refiners.

Of the metals, tin, nickel, and aluminium are the only important ones offering much possibility of control through ore ownership. The world's known reserve of tin ores is small, and a company using much of the metal might do well to insure against extortion by owning part of the supply; for the annual output is cornered with some frequency. Nickel is also scarce, or rather it occurs at only a few points in workable tonnage. Aluminium has been controlled rather through patents than by ore ownership, though the latter element also is supposed to exist.

Lead and silver, produced mostly as by-products, could not

possibly be controlled through ore ownership, but on the other hand offer distinct opportunities for the refineries. Iron ores cannot be controlled as to tonnage, and as yet no control exists on any saner basis. The same may be said of coking coal, or of bituminous coals in general. The investment required would make mine control impossible commercially.

The situation as regards anthracite coal is very different from those which have been noted, and furnishes the weakest point in the entire matter. The companies involved have not been notable for their tactful handling of a question which required very careful treatment; and the results of the pending suits may easily be more surprising than pleasant.

Finally, the copper situation can not be discussed adequately here, and it can only be said that no successful control of copper prices has ever been based upon actual monopolistic ownership of mineral properties.

As a summary of the entire matter, it may be said that except in a few very unimportant instances price control is never based upon monopolistic ownership of mines or mineral properties.

THE CONSERVATION OF IRON-ORE RESOURCES

In several of the preceding chapters of this volume it has been necessary to allude casually to the Conservation Movement which became so striking a feature of the political landscape during the second administration of President Roosevelt, and it is possible that the allusions were not always made in the most respectful manner. The disrespect, however, is not due to the conservation idea itself, for that deserves very careful attention; but to the way in which its more extreme advocates attempted to support and execute it. In this regard the Conservation Movement merely shared the fate of all reforms. All of our past experience goes to show that any new and important view as to government policy will inevitably, at the outset, meet with so much opposition and ridicule that its supporters will finally take a far more advanced stand than if the reform had been accepted quietly. The result is, of course, that there is a very violent expression and execution of the reform, followed by a natural reaction from the excess of reform; and then, at a later time, the matter is taken up again and put into execution in a reasonable

way. As regards conservation of natural resources we seem to have passed through the successive stages of earnest enthusiasm, of extreme and senseless popularity—and of reaction. It is now possible to discuss the matter without treating it as a purely partisan affair.

Whatever extremes it may have been led into later, the Conservation Movement at the outset had a very sound basis of fact and argument. It is true that certain of our natural resources are being wasted or used uneconomically. Since this enhances the cost of the output, and decreases the total supply, it is a matter of general public interest, and not merely a private business affair. It is idle to say that an owner may do as he pleases with his own property. We know, as a matter of fact, that as soon as he develops ideas in this regard which run counter to sound public policy, a way will be found to control the situation legally.

The waste or uneconomical use of a natural product such as timber is serious, but is it obviously far more serious when the product wasted is one, like ore, which does not reproduce itself. If it could be established that existing conditions as to ownership do encourage waste of ore, there would be some reason to place legal restrictions upon such private rights as led to such waste. But, unfortunately for this particular application of conservation principles, it has never been suggested by any competent authority that private ownership of iron mines leads to waste of ore. It has, however, been pointed out that excessive competition among a multitude of small owners may very easily lead to extravagant and wasteful mining methods; but that is an argument in favor of the large corporation as against the small owner. On that account it is not pressed to the front by advocates of government control, even though its truth is commonly accepted. Bearing in mind the enormous ore reserves known to be available, it is difficult to find any good reason for advocating government control of the iron-mining industry, based on any theory as to the necessity for conservation.

In discussing the conservation of iron ores, it is still necessary to limit consideration to its effects on the welfare of the country in which one lives. There may come a time when national boundaries will be of merely historic interest, and when the nations will compete in friendly rivalry for the privilege of doing each other the most good. The man of that time—if indeed that sex

has much to say about the matter—will be able to say with truth that he looks upon the whole world as his country. But at present, though certain of the purer spirits of the Peace Congress have already attained that advanced stage of enlightenment, the world in general is still unconvinced. The nations still compete for business, with little of either kinship or kindness apparent, and we must still take a national view of any public policy. Disregarding the distant outlook, we must deal with conditions as they are, and as they affect the United States.

Such restriction of ideas and policies suggests that, though no obstacle should be placed in the way of the cheapest possible development of our own iron ores, the most effective conserving agent will be the free use of foreign ores whenever they are economically available. This implies that our tariff against foreign ores, in force until quite recently, was an economic mistake; and that it should not be replaced under any circumstances. Further, it implies that export duties levied by foreign governments upon ores which may reach our furnaces are, in reality, discriminations against our steel industry.

The Taxation of Iron Ores.—Another point of contact between Governmental and private activities is furnished by the taxation of ores and of ore reserves. Until recently this was hardly a matter of serious interest, for in the older states the general practice has been to tax mining property on a basis roughly corresponding to the value of machinery and improvements in sight, and to pay no attention to the possible value of the ore reserves.

In the Lake Superior region, however, other methods of taxation have been devised and put in force—or perhaps it would be fairer to say that taxation has actually been made methodical. For, whatever we may think of the different methods in use in the Lake states, they all have at least the merit of being exact and based upon intelligible rules.

Both Minnesota and Michigan levy a tax upon iron-ore reserves, but the two methods differ sharply in their underlying theory and in their practical effects. Minnesota divides the ores into a number of classes, classified according to ore grade, accessibility and other factors; and then assigns a certain tax rate per ton to the ore of each class. Michigan based its tax system upon the probable net annual return from the various properties, so

that though expressed as an ore reserve tax, it is really a tax upon probable net earnings. From the economic point of view, the Michigan plan seems to be sounder than the Minnesota plan, though of course the relative effects of the two plans will be really determined by the manner in which the different theories are actually put into practice.

After having been mined, iron ore of course becomes personal property, and as such is taxable at any point on its journey where it remains long enough for a valid taxing right to be established. In the case of the Lake Superior ores, there are three points at which ores are normally carried in sufficient quantity to make this possibility of interest. The three stocking points are (1) at the mines and upper Lake docks; (2) at lower lake docks and at (3) the furnaces. Since the states of Michigan and Minnesota have already taxed the ore in the ground, no fair claim could be set up to place an *additional* tax on ore in stock-piles in the Lake Superior region. With regard to lower lake ports the case is different, and here at least one state—Ohio—is ready to levy a tax on ore in transit. In discussing the transportation of ore from the Lake Superior district to the furnaces, it was noted that the stocks of ore carried through the winter at ports on Lake Erie are increasing each year.

The figures on page 209 will serve to give some idea of the ore tonnage normally carried at Lake Erie ports through the winter, and which may now be subjected to local taxation.

In considering the effects of taxation in this connection, it will be well to bear in mind that the levying and collection of a tax, whatever its nature, does not create wealth. It merely takes wealth from one class of citizens and turns it over to the government to be spent, theoretically, for the common good. In the case of a special tax on an article of commerce or industry, such as we are now considering, it is obvious enough that the original payer of the tax will not assume the burden permanently, but will shift it as promptly as possible to the purchaser of his goods, by raising prices to cover the tax. This process, carried out at each stage of the industry using goods, finally results in causing the "ultimate consumer" to pay higher prices for the finished product.

Export Duties.—The question of the ultimate payment of tax burdens becomes a matter of still broader interest when the tax

is levied in the form of an export duty on ore. Several countries have done this, for several different reasons. It is justified commonly on the argument that ore mining does not imply as much industrial development or wealth creation as steel-making; and that consequently the country may reasonably levy a tax on exports of raw materials designed for finishing in another country. Sweden, Spain, Brazil and Newfoundland have, in one form or another, levied export duties on iron ores. In the cases of Spain and Sweden the issue is frankly stated; in Brazil it takes the form of a port tax; in Newfoundland a royalty was levied as a substitute for a proposed export tax.

The effect of an export tax will differ, according to competitive conditions. When the ore so taxed is being taken by a furnace district which requires it very much, the amount of the tax can usually be added to the price of the ore. But when the taxed ore is subject to keen competition from ore mined elsewhere, the tax can not be so shifted to the furnace, and in that case it falls as a direct burden on the miner

CHAPTER XXXII

QUESTIONS OF PRIVATE POLICY

As in dealing with questions of public policy, the preceding discussion has left untreated, or inadequately treated, certain matters relating to the proper policy of individuals and corporations with regard to iron-ore reserves. The present brief chapter will touch upon some of the more important of these questions, and will suggest certain points which, in the opinion of the writer, are deserving of consideration.

Reasons for Reserve Ownership.—In an earlier chapter of this volume, it has been pointed out that the ownership of large ore reserves implies a steady burden upon the company owning them; and that there are actual financial limitations to excessive reserves, regardless of legal or other considerations.

This line of argument might be extended, of course, to operate as an objection to any ownership of ore reserves whatever; and it is perfectly true that if a company were assured of being able to cover its ore requirements in the open market, during twenty or thirty years to come, it would not be financially justified in owning ore reserves, unless they were obtainable at a bargain price.

But it would be difficult to give such assurances in most cases. The merchant ore market in the Lake Superior district is large, but for a large steel company to depend entirely upon merchant ores would be considered hazardous by most people. It should at least own sufficient tonnage to be sure that, under no circumstances, would it be entirely at the mercy of general market conditions. It might not use this owned tonnage in normal years, but it should be there ready for use. If the ownership involves extra costs, they may fairly be looked upon as insurance against the possibilities inherent in a boom year.

For companies not located along the Atlantic coast, or within the Lake Superior shipping radius, the argument for ownership of ores is even stronger. For in other areas there is practically no merchant tonnage on which one could depend in any year.

Further than this, there are reasons connected with the financ-

ing of steel companies which practically force the ownership of large reserves. With the exception of a few small and particularly strong companies, dependence for funds is on one or more of the great banking houses. During recent years there has been a growing tendency, when furnishing funds for expansion and development, to insist upon the ownership of large raw material reserves. The banking view, due perhaps to official and other hysteria over raw material exhaustion, is that the ownership of such reserves constitutes a guarantee of higher value than the other tangible and intangible assets. Perhaps this idea has been too strongly emphasized at times, but it is substantially sound after all, and so long as it is commonly accepted among financial houses it must be reckond with by manufacturers.

Ore Reserves and the Banking House.—The industrial reasons for holding relatively large reserves have been discussed in an earlier chapter, and the financial considerations which operate to place a maximum limit on reserve holdings have also been noted. There is, however, another point of contact between financial conditions and ore reserves which requires some consideration, for it has afforded one of the more pressing reasons for the accumulation of such reserve tonnages.

Until the development of the great consolidations some twenty to thirty years ago, the relation between the banking house and the steel or iron company was limited in extent, discontinuous, and comparatively unimportant in effects. In the cases of a highly successful firm or closely held corporation, this is still true. Such industrial units as the old Carnegie partnership, the Jones and Laughlin Company of the present day, and such successful smaller units as La Belle and Woodward are only indirectly dependent upon banking support and direction. Industrial units of this fortunate type are not, therefore, steadily and normally subject to banking opinion in the conduct of their business.

In the case of the majority of corporations, however, the relation between the manufacturing company and the banking house has become very intimate, continuous and important in its effects. It has affected the question of ore-reserve ownership to a very striking degree, through the way in which bankers have in recent years laid stress upon the desirability of raw-material control. Ten or twelve years have sufficed to bring about a very definite, though rarely clearly stated opinion in this regard, and it will

be of advantage to trace briefly the stages of its growth, and to attempt some forecast of its probable future trend.

After a few years of operation had shown that the newly formed Steel Corporation was able to weather industrial storms, circumstances brought about public statements by several prominent officials. Made in the first flush of success, some of these statements contained elements of later trouble, and have since been repented in sackcloth and ashes. However we may look upon them now, these statements had a very obvious and definite effect upon public opinion in general, and upon banking opinion in particular. To the casual reader it seemed certain that one very important element in the success of any steel company must be the ownership of ore reserves, and of very large ore reserves at that. To the banker there was the additional appeal, that only through ownership of such reserves could there be any guarantee of the ultimate value of a bond issue.

A few years later came the pessimistic Swedish estimate of world reserves, and our own Conservation movement, both of which have been discussed in an earlier chapter. Taken together with the prevailing industrial sentiment, there is no reason for surprise that insistence upon huge raw-material tonnages became a cardinal principle with many banking houses. It is probably safe to say that for some eight or ten years past there has been little chance of raising money for any new industrial enterprise unless more than adequate reserves of coal and ore could be shown.

Perhaps the matter was overdone, but there was an element of truth in the prevailing opinion, and it would be unfortunate if recent discussions caused a reaction in the other direction. It is still advisable for a steel company to own ore reserves, and large ore reserves. But we must limit our ideas as to the possibility of monopolistic ownership on a mere tonnage basis, and we must pay more attention to other factors. The thing that counts is not the mere ownership of enormous tonnages; it is the control of the most desirable tonnages. The United States is full of unmined ores, but nothing can shake the dominance of the Lake ores over the best portion of the American steel market. The world has ample supplies of ore scattered widely over its surface, but among them all it will finally be found that one is so located that its control will enable its owners to dictate price policy on both coasts of the Atlantic. It is not mere tonnage that must

be aimed at, but grade, location, mining costs and shipping advantages.

Effects of Overvaluation.—A question which still remains to be considered relates to the effects of overvaluation of ore reserves on the various parties who may be considered to have rights in the matter. One phase of this subject has already attracted considerable public attention, and in an earlier chapter it was pointed out that one of the principal complaints against the existing status of ore ownership was based upon the view "that, regardless of extent of ownership, the steel companies are in a position to earn excessive profits on their finished steel because of assumed excessive valuations placed on their ore reserves." This view will be discussed now, but it is not the only thing which requires attention in this connection, for if overvaluation exists it is far more detrimental to other parties than to the consumer of the finished product. It is easy enough to make vague general statements as to the effects of overvaluation, but as these may lead to erroneous conclusions, it will be better to start from a definite basis and follow out closely the different effects which will arise from an initial error in valuation. For our present purposes we may assume the case of a steel company having ore reserves amounting to one thousand million tons. We may further assume that a fair present valuation for this ore would be fifty cents per ton; but that for one reason or another the company has carried it at a valuation of one dollar per ton. What effects will spring from this overvaluation; and how will the company itself, its security-holders, its competitors, and the consumers of its product be affected?

First of all, it is obvious that in our assumed case, the assets of the company, as shown on the balance sheet, are greatly inflated, for ore properties which should be given a total value of five hundred million dollars are being actually carried at a valuation of one thousand million dollars. The effect of this upon the stability of the company itself, and on the prospects of its security-holders, will depend on how this excess is balanced on the other side of the sheet. It is clear that there is a large nominal value which could not be realized on, and if bonds have been issued to such an extent that any part of their security depends upon the ore valuations, the security of the bonds and the stability of the company will both be affected very

seriously. On the other hand, if the bonds are secured by other physical property, and the excessive ore valuation is balanced merely by stock issues, the stability of the company will not be endangered but the stock issues will show, by their market price, that the public has discounted the overvaluation. Investors who bought any of the issues without knowledge that the assets were unfairly valued will find that both the security of their issues and their market value have depreciated when the truth becomes known. New investors, however, can not complain on either ground.

Turning to the effects of overvaluation on operating conditions and competition, it is to be noted that the company which has practised it at the outset will have to pay for it each year. If our assumed company uses 40,000,000 tons of ore annually, to make 20,000,000 tons of steel, it will have to charge off $40,000,000 per year for amortization of ore reserves. A competitor of the same size, which has valued its ore fairly, will have to charge off only half this amount. If the two companies sell their steel at the same average price, the conservative company will actually show $1.00 per ton more profit than the other. So far as competition is concerned, overvaluation therefore offers difficulties, and not advantages.

Finally, the question arises as to the effects of overvaluation of raw materials on the prices of finished products. In private life even the wording of the question would determine the answer, for no one imagines that a merchant, by overcharging the *cost* of his goods, can really sell them for higher prices than do his less imaginative competitors. It is certain that, in similar fashion, no amount of overvaluation of ore reserves can possibly have the slightest effect upon the selling price of finished steel. The price of the steel will be regulated by competition; if there be no free competition, it may be regulated by combination; but in neither case will an imaginary valuation placed upon ores have any effect whatever on the matter. It is true, on the other hand, that overvaluation of the ores will serve to conceal the true rate of profit, but that is equally true of overvaluation of any other part of the capital used in the industry.

To sum up the matter, it may be said that overvaluation of ore reserves puts the balance sheet on a permanently false basis, and on this account alone it is reprehensible. Its effect on the

company and on holders of securities will be either dangerous or merely objectionable according to the kind and amount of securities outstanding against the ores. So far as new investors are concerned, the effect in either case is negligible, for it will have been discounted by market prices. With regard to competitors, overvaluation places the company practising it at a distinct disadvantage. So far as consumers are concerned, overvaluation is of no interest. It may conceal profits, but it can not produce them.

The Strategic Value of Large Tonnages.—There is one phase of the matter of iron-ore reserve valuation which is rarely alluded to in print, and not commonly given its proper value in corporation practice. Reference is made to the technical and moral value possessed by very large reserve tonnages, over and above the value which they would have as mere aggregations of ore. It is obvious that there are certain difficulties in the way of free discussion of this subject, for the proper commercial utilization of such large reserves may involve acts or suggestions which a zealous government would consider as tending to restrain trade. But it is at least possible to outline the subject broadly, in the hopes that actual developments will in later time serve as more definite illustrations.

From the purely technical standpoint it would be safe to assume that if an iron-ore deposit containing fifty million tons of ore is worth a certain sum, an exactly similar deposit containing five hundred million tons would be worth exactly ten times that sum. This is true technically, but not commercially, because in passing from a fifty million ton reserve to a five hundred million ton holding, we have in reality gone across a very important border line between two entirely different classes of holdings. A deposit containing fifty million tons of ore must be valued merely as incidental to the existing iron industry; it will not induce or justify any extensive departures from current metallurgical practice of furnace locations. Its ore must be valued by the ton, in competition with other ores.

But in dealing with ore reserves figuring up in the hundreds or thousands of millions of tons, the conditions are changed more radically than is commonly understood. A fifty million ton deposit must be of well-known and purely conventional type before interest will be attracted by it. A five hundred or

thousand million ton deposit on the other hand, may show very uncommon ores or mining conditions without seriously affecting its value. The large tonnage will justify the extensive investments in mining and transportation which may be necessary; it will justify attempts to modify concentrating or metallurgical processes to fit the new ores; it may bring about a shift in the location of furnaces and steel mills.

These essential differences in value between ordinary and very large holdings may be better brought out if concrete examples are suggested. Fifty million tons of low-grade aluminous ore does not sound inviting, but the three thousand million ton reserve in Cuba is distinctly a commercial factor. One hundred million tons of ore in the interior of South America, even if of exceptionally good grade, might lie undeveloped for several more centuries; but the existence of seven thousand million tons in Brazil can not be overlooked industrially. Fifty million tons of ore lying in a bed under the Atlantic Ocean, so as to require submarine mining, would hardly affect the steel trade; but the four thousand million tons of Newfoundland may be the most important single factor in our next stage of progress.

It will be seen that there is a distinct additional value attaching to very large ore holdings, this additional value being entirely out of proportion to increase in mere tonnage. It is difficult, if not impossible, to express it in figures, but it certainly exists and must be allowed for in any valuation of such holdings. As soon as an ore-holding reaches a size to justify changes in metallurgical practice or plant location, its ores acquire a technical and moral value far above that which they would have if merely sold on a competitive basis in an open ore market.

It may be that the present guardians of our political freedom and business relations might object to the use of the word *moral* in the last paragraph, and point out that some of the implications which could be drawn from this statement of the subject might result in business transactions not entirely consonant with the principles of the New Freedom. This may be admitted, but fortunately the examples chosen were selected from ore deposits occurring outside our borders; and the most important of them is in a colony ruled by law and Englishmen. Of course large ore tonnages, as well as small, can be utilized by smelting into iron and conversion into steel; and the present discussion merely

suggests that, under certain circumstances, they have other utilizations which give them additional value.

The Low-cost Producer.—It is entirely conceivable that a single corporation might control 60 percent of the steel output of a country, without being really in a position to exert much influence on prices. This situation would exist if its 60 percent did not include the low-cost production of the country, for in the long run it is the low cost producer who will fix the minimum prices during depressions, and who will come close to fixing the average range of prices during normal times. The only time that a high-cost plant has much effect on prices is during abnormal booms, when the maximum price obtained is likely to be determined by the cost at the dearest mill.

This gives the low-cost producer a strategic importance entirely out of relation to the size of its output, provided only that this output is sufficiently large to make some impression on the general market. Those who have kept in touch with the copper situation during recent years will realize this, and can offer in proof the manner in which one mine has served as a weapon in price disputes. The same thing applies to the steel business, and indirectly to the section of it in which we are at present interested—the control and handling of iron-ore reserves.

Elsewhere I have stated, in very strong terms, the opinion that anything like monopoly of iron-ore reserves is now impracticable owing to the tonnages which would have to be taken into account. That statement does not require any qualification, but it must be read in connection with the present section before its bearing is fully understood. *The company which controls any large tonnage of the cheapest ore in the world, or the cheapest portion of the ore supply of any given furnace district, does not need to strive for monopoly. The advantages of monopoly come automatically to the low-cost producer. And they come in a way which is both legal and legitimate.*

The question of effective monopoly, therefore, does not depend entirely upon the percentage of an industry which is controlled by one company; but upon the ownership or control of the critical or low-cost portion of the industry Without this, mere size will avail little; with it, price control may usually be made effective without necessarily acquiring any preponderating percentage of the industry.

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